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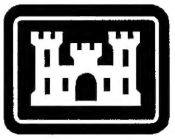

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Procedures for the Evaluation of Sheet Membrane Waterproofing

Charles J. Korhonen, James S. Buska, Edel R. Cortez, and
Alan R. Greatorex

August 1999

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Abstract: Sheet membrane waterproofing has been used to protect bridge decks against water and deicing salts by transportation agencies in New England for more than two decades. Though such membranes have proven useful at extending the useful life of bridge decks, there are no convenient methods to evaluate one membrane against another. This report details the genesis of blisters, a major problem for membranes, and defines test procedures to evaluate sheet membranes based on their ability to adhere to concrete, accommodate strain, resist puncturing, and pass water vapor. The results of these tests allow an engineer to compare sheet membranes based on material properties but they, alone, cannot be used to predict how well a membrane will perform in practice. Because a laboratory environment does not reflect the complex combination of forces and deterioration mechanisms a membrane is exposed to in the field, a follow-on study of the installation/design process and long-term performance of membranes in actual bridges needs to be conducted. This report provides a needed step toward the ability to predict sheet membrane service life.

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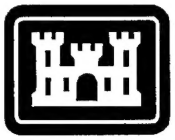

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Prepared for
NEW ENGLAND TRANSPORTATION CONSORTIUM

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PREFACE

This report was prepared by Charles J. Korhonen, James S. Buska, and Edel R. Cortez, Research Civil Engineers, and Alan R. Greatorex, Civil Engineering Technician, of the Civil Engineering Research Division, U.S. Army Cold Regions Research and Engineering Laboratory.

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The authors thank the following members of the NETC Panel for technically reviewing the manuscript of this report: Guy Berthiuame, Thomas Breslin (chairperson), Craig Graham, David Hall, Deborah Loiselle, and Michael Sock.

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Departments of Transportation, and the Land Grant Universities of the six New England States, or the U.S. Department of Transportation's Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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Procedures for the Evaluation of Sheet Membrane Waterproofing

CHARLES J. KORHONEN, JAMES S. BUSKA, EDEL R. CORTEZ, AND ALAN R. GREATOREX

INTRODUCTION

At the request of the New England Transportation Consortium (NETC), the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) conducted laboratory studies from March 1998 to March 1999 to standardize procedures to evaluate bridge deck membranes. This report presents the results of these studies and completes the requirements of NETC Project Number 94-3.

Background

Waterproofing membranes have been used to protect concrete bridge decks by transportation agencies in New England for more than two decades. Over the years, membranes have proved useful for preventing water and deicing salts from penetrating the concrete and corroding the embedded reinforcing steel. Frascoia (1983), in his 11-yr field exposure study of 33 membrane systems, demonstrated that brushed-on coatings of coal tar emulsion significantly reduced the ingress of chloride into concrete, though not as efficiently as sheet systems. Unprotected bridge decks absorbed 6.97 lb/yd^3 (4.11 kg/m^3) of chloride ions in the top inch of concrete, but the decks absorbed only 0.65 lb/yd^3 (0.38 kg/m^3) when the concrete was coated with tar emulsion and 0.50 lb/yd^3 (0.30 kg/m^3) when a sheet membrane was used on top of the concrete. However, tar emulsions have not provided consistent protection and were judged by the Vermont Agency of Transportation as unacceptable. Because chloride does not seriously corrode rebar until it reaches at least 1.30 lb/yd^3 (0.77 kg/m^3) (Lewis 1962, Clear 1974), an interlayer waterproofer should thus be an improvement and considered as an important bridge element.

Bukovatz et al. (1983) provided a similar endorsement of waterproofing systems when they characterized the performance of sheet and liquid membranes as satisfactory after 12 to 16 years of field exposure. Wojakowski and Hossam (1995) later reevaluated six of the eight membranes studied by Bukovatz et al., concluding that the general performance of the membranes had decreased significantly. After 25 years of service, they estimated that the lives of some systems had been exhausted. Frascoia (1993) projected that the membranes he studied would provide protection from salt contamination for more than 50 years.

A membrane will protect a deck only if it is installed properly, stays intact, and remains firmly bonded to the deck; cracked or poorly bonded membranes can lead to serious roadway deterioration such as cracking and potholing. Construction is a crucial time in the life of a membrane, because it is during construction that most problems begin. For example, membranes are subject to abrasion damage from foot and vehicle traffic, puncture from dropped objects and rocks pressed into the membrane, and poor adhesion due to inadequate workmanship, inclement weather or material defects. Poor adhesion can also result from the deck surface being too rough or uneven. Whatever the cause, inadequately installed membranes tend to puncture, blister, and crack at some point during their service life, which weakens a membrane to chloride and moisture penetration and ultimately results in failure of the overlay pavement. In turn, this accelerates deck deterioration and presents rough surfaces to the motoring public.

Objectives

Though field tests have proven that membranes reduce chloride contamination of underlying concrete, there are problem areas where improvements in test procedures or materials are needed. If a membrane cannot be fully adhered to the deck, or it somehow becomes damaged during construction or is unable to resist splitting when cracks develop in the underlying deck or bituminous overlay, moisture and chlorides can leak through the system and accelerate bridge deterioration. The objectives of this work were to develop laboratory tests for evaluating sheet membrane waterproofing for their ability to resist cracking, blistering, and puncturing. ASTM lists a number of tests to evaluate various engineering properties of tape, rubber, roofing, plastics, and geomembranes. The problem is that there is no group of standards, or ways to interpret them, that all manufacturers follow when reporting performance data for their products. As a result it is difficult, if not impossible, to rate one membrane against another based on manufacturer-supplied data. Our plan was to review these and other literature to develop a set of testing standards specific to the above objectives.

Approach

NETC developed a list of sheet membranes that have been used on bridge decks in New England. From that list we invited suppliers of membranes to participate in this study by providing materials and by making test samples. (Several suppliers of liquid membranes were also interested in participating but were not accommodated, because testing liquid membranes was not within the scope of this study.) The intent of this work was to recommend tests to evaluate one membrane against another. We acknowledged that until a systematic field test is conducted, these laboratory tests could not reliably predict expected service life, as laboratory tests do not simulate field conditions and, therefore, only suggest possible outcomes in the field.

This project subjected sheet membranes from the six manufacturers shown in Table 1 to the following four tests:

- ***Adhesion***: to evaluate the adhesion developed between a membrane and a concrete substrate.
- ***Tensile strength and elongation***: to determine how well a membrane can resist and accommodate movement of the concrete deck.
- ***Puncture resistance***: to measure the resistance of a membrane to rock puncture.
- ***Water vapor permeance***: to determine how easily water vapor can pass through a membrane.

Table 1. Membrane manufacturer and product tested.

Manufacturer	*Product*
NEI	AC Bridge and Deck Seal
Polyguard	665 LT
Protecto Wrap	M140A-R
Royston	10AN Easy Pave ER
Soprema	Sopralene Flam Antirock
WR Grace	Bituthene 5000

For reference and general interest, Appendix A presents technical data from manufacturers' brochures for each membrane evaluated in this project.

ADHESION

Lack of adhesion is considered to be the leading cause of membrane blistering. This study reviewed current testing standards, such as ASTM C794, D903, and D1000, and developed one that could be used as the standard by which to evaluate the ability of sheet membranes to adhere to concrete.

Procedure

Adhesion was measured by peeling strips of membrane off mortar. The test consisted of adhering membranes to carefully prepared mortar surfaces, cutting the membrane into strips, and applying a tensile load at a constant rate of extension until each strip peeled off the mortar a predetermined distance. Test specimens were prepared, as shown in Figure 1, according to manufacturers' recommendations. Two sets of test specimens for each of the six membrane types were constructed: CRREL made three specimens and the membrane supplier made three. Making two sets of samples helped to determine if choice of applicator influenced results. The specimens were prepared as follows:

- At room temperature, mix one weight of Type I portland cement with two weights of Ottawa sand (20–30 grade) according to ASTM C305.
- Cast mortar into 6- × 6- × 21-in. (15-× 15-× 53-cm) molds and cover with sheet of plastic.
- After 24 hours, strip molds and cure mortar beams in room-temperature limewater for 14 days.

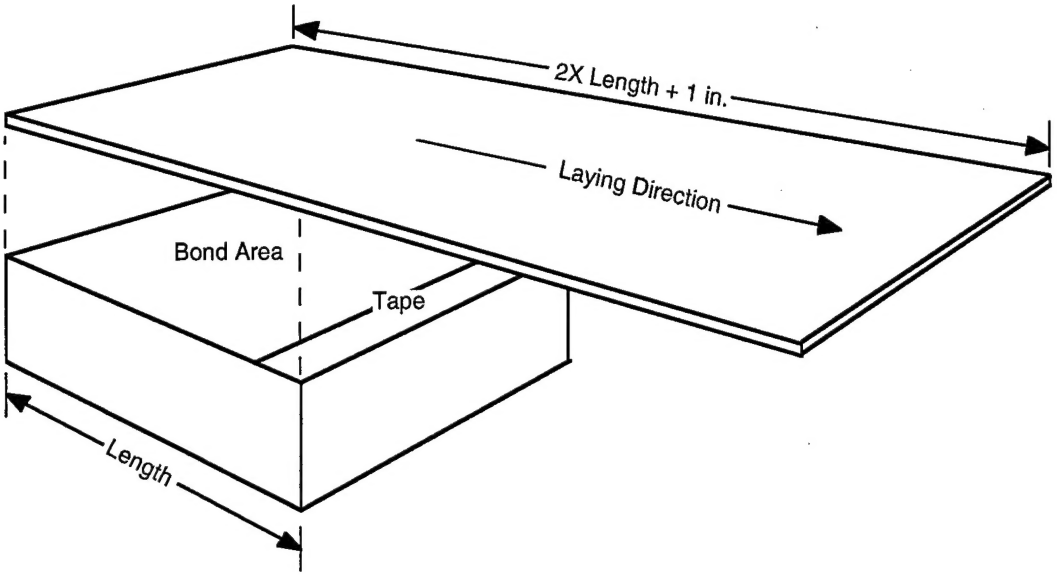


Figure 1. Fabrication of test specimens.

- Cut beams into 6- × 6.38-in. (15.2- × 16.2-cm) slices.
- Sand slices (slabs) with 24-grit silicon-carbide sandpaper until surface is flat and all saw marks are removed.
- Oven dry the mortar slabs at 220°F (104°C) for 24 hours.
- Clean sanded surface with dry, stiff fiber bristle brush.
- Place 0.75-in. wide strip of tape across one end of slab.
- Apply primer to the test surface.
- Allow primer to cure to a tack-free finish.
- Apply membrane according to manufacturers' instructions.
- Condition specimens at approximately 70°F (21°C) and 50% RH (relative humidity) for a minimum of 14 days.
- Cut membrane into five 1-in.- (2.5-cm) wide strips through to the mortar with a sharp razor knife.
- Start cuts 0.50-in. (1.3 cm) from edge of slab.

Figure 2 shows the test setup. Five strips of membrane were peeled off each slab back at an angle of 180° at a grip separation rate of 4 in. (10.2 cm)/min. Force and grip displacement were recorded for each strip. Slippage in the grips and membrane stretching are discounted, grip displacement is exactly twice membrane displacement. Before discussing the significance of the adhesion test data, we will first consider the mechanics of blistering.

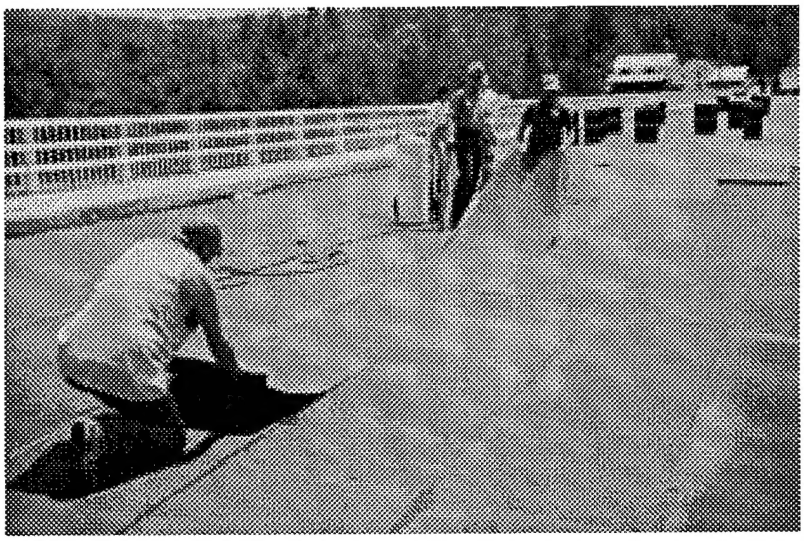
Blister mechanics

In a related study, Korhonen (1986) pointed out that roof membrane blisters develop from voids built into a roof during construction. There is no reason to suspect that bridge blisters are any different. They probably are caused by the expansion of air pockets inadvertently trapped between the membrane and the concrete deck during construction. Roughness of the concrete deck, unevenly applied or inadequately cured primer, debris, and moisture are among a number of reasons that can impair the adhesion of a membrane to a deck and lead to blister-causing voids. On the other hand, a perfectly adhered membrane (if it exists) cannot blister.

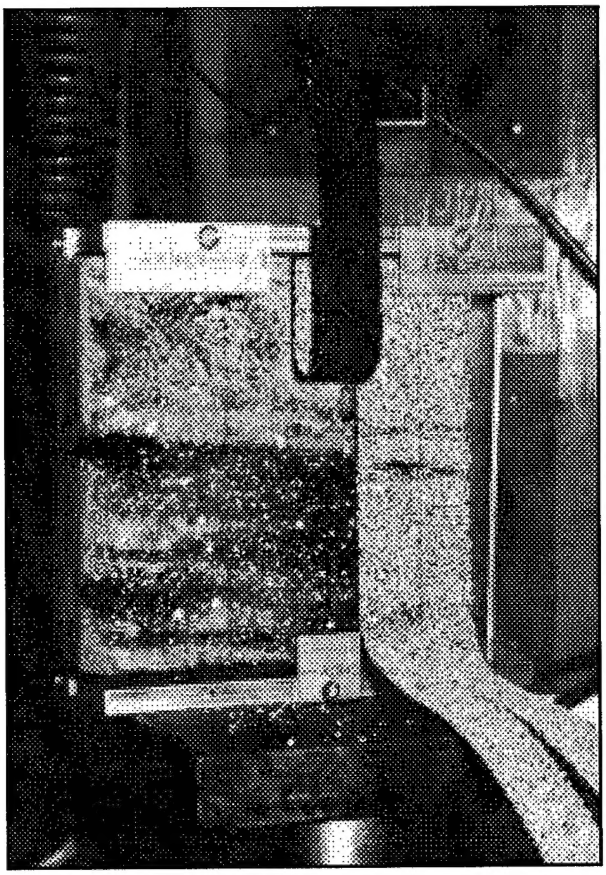
Fortunately, a membrane does not have to be perfectly adhered to a deck. Mathematically, it can be shown that some voids are acceptable. When blisters form, they appear as slightly bloated humps—in the membrane or the overlying pavement—several inches to a foot or two in diameter. They often occur soon after the membrane is laid or immediately after hot-mix pavement is placed on top of the membrane. As eq 1 shows, growth happens only when the air inside a void is heated sufficiently to push the overburden upward and peel it off the deck:

$$F = (PA - WA)/L \quad (1)$$

where F = membrane-to-deck peel strength
P = internal pressure



a. Installing a membrane.



b. Peeling membrane strip from mortar slab.

Figure 2. Typical installation and adhesion test setup.

A = area of void (πr^2)
W = overburden (weight of material on top of blister)
L = perimeter of void.

Equation 2 explains that the smaller the void, the less likely it is to develop into a blister:

$$r = 2F/(P - W) \quad (2)$$

where r is void radius. That is, it requires more internal pressure (heat) to expand a small void than to expand a large one.

Figure 3, developed from eq 2, illustrates this concept. It consists of four graphs, each composed of three curves, where each curve represents peel strength plotted against temperature and critical size. Each graph defines the smallest void expected to blister. For example, if an air pocket beneath a membrane adhered to a deck at 5 lbf/in. (875 N/m) is heated from 70° to 140°F (24° to 67°C), a 5.2-in. (13.2-cm) radius would be the smallest void that could blister (Fig. 3a). However, if the air beneath the membrane is continually water saturated, the critical void would reduce to 2.25 in. (5.7-cm) radius (Fig. 3b). Of course, higher bond strengths are more resistant to blistering, but one must realize that heat, the driving force of blisters, softens the adhesive and diminishes peel strength. Thus, the 5-lbf/in. force used in the above analogy is considered conservative, even though some membranes adhere more tightly to concrete at room temperature.

The situation changes as soon as the membrane is topped with hot pavement. In this case the void immediately heats up to 250°F (146°C) or more and

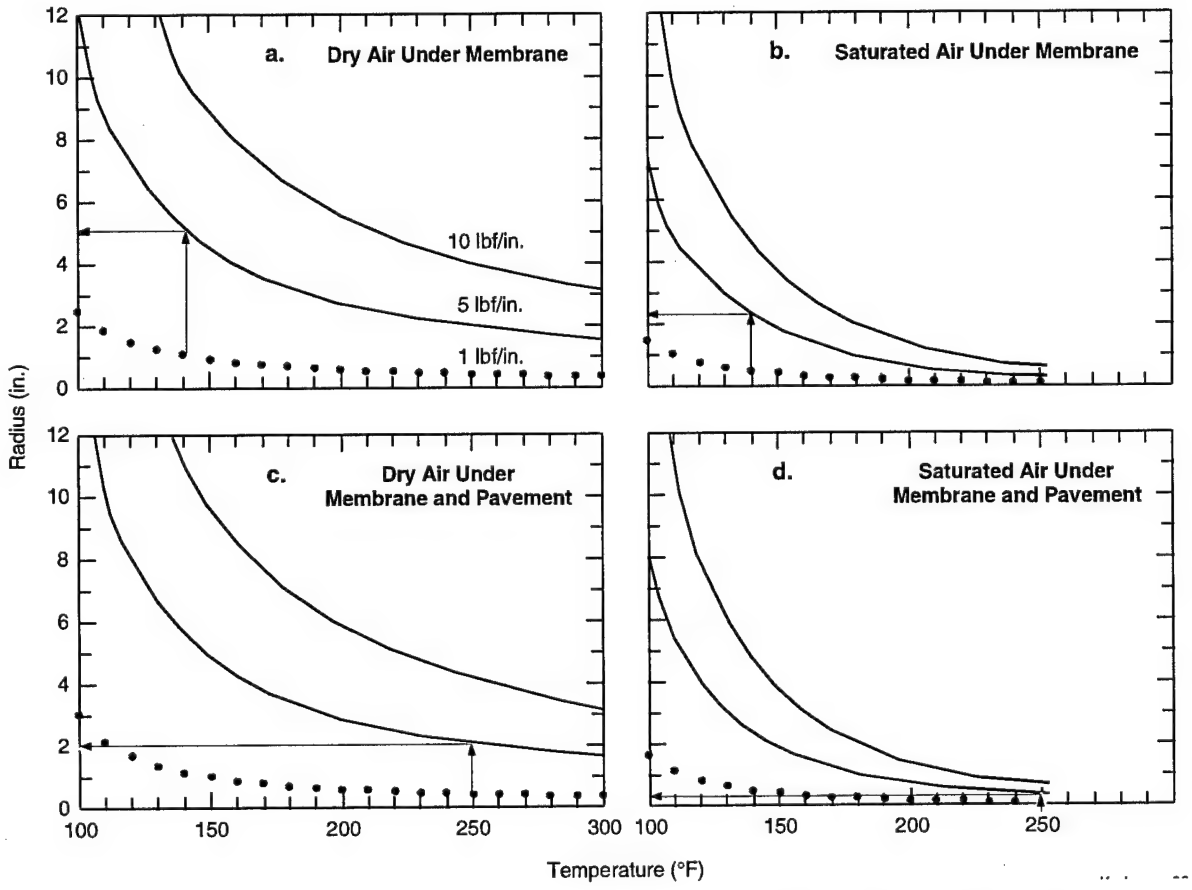


Figure 3. Relationship between minimum void size, peel strength, and internal void temperature. Blister pressure, which relates to temperature, was determined by considering dry and moist air to be ideal gases. The temperature of 70 °F (21 °C) represents atmospheric pressure.

its overburden increases more than 20-fold (a membrane weighs between 0.002 to 0.008 lb/in.^{2} whereas 2-in.-thick asphalt pavement weighs approximately 0.168 lb/in.^{2}). In this situation we see that the critical size changes from a 2.1-in. (5.3-cm) radius when the void space is dry (Fig. 3c) to a 0.30-in. radius when it is wet (Fig. 3d). Moreover, blisters do not just expand once, they continually increase in size. Korhonen (1986) found this to be true for roof blisters as did Hironaka and Holland (1986) for pavement blisters. Thus, once a blister initiates, no matter how small it may be, it eventually grows large enough to become a big problem.

Though Figure 3 represents idealized situations (a blister is not rigid and self-contained), clearly a nonporous membrane exposed to the sun will remain blisterless if its voids are smaller than 5.5 in. (14 cm) across (Fig. 3b). When exposed to the intense heat of freshly laid pavement, approximately quarter-sized voids (0.9 in., or 2.4 cm) (Fig. 3d) can lead to problems. Other scenarios are possible for blisters but the quarter coin size should be useful as a rule of thumb for bridge inspectors to distinguish when a membrane is being inadequately adhered to a deck. A permeable membrane can reduce blistering by allowing pressure build up to escape through the membrane. However, the section on water vapor permeance reveals that the membranes in this study were not very breathable.

Results and discussion

The entire data set for the adhesion tests consists of force-displacement diagrams for 157 strips of membrane peeled off mortar slabs (App. B). We will not discuss each diagram but, rather, summarize them in Figure 4 and make specific references to them in the following text to give the reader a sense of their significance. The reader is encouraged to peruse Appendix B for added detail.

Figure 4 shows six force–displacement diagrams, one for each membrane type where each is composed of two curves (except for Figure 4f, where supplier samples were not available). As can be seen by the difference between the two curves in each graph, the choice of applicator can influence results. Each curve represents the average of up to 15 strips peeled from three samples fabricated by the membrane supplier compared to three done by CRREL. The Figure 4 curves reveal that testing was done in two stages. In the first stage, approximately 2 to 2.25 in. (5.7 cm) of the membrane was peeled off the slabs. The membrane was then unloaded, repositioned in the grips—as the grips reached the end of their movement—and peeled approximately another 2 in. (5 cm). In interpreting the curves, one should recognize that the pulling force for each stage gradually built up, as the membrane and adhesive stretched and as the membrane seated in the grips, until the force became large enough to progressively peel the membrane from the slab.

The shape of each curve shows that adhesion is a complex issue, difficult to describe with just one number. Should a maximum, minimum, or average force be used to describe adhesion? Maximum values can be considered as the very best adhesion that one can hope to expect. It could be argued that the resistance offered by a membrane just prior to the onset of progressive peeling sometimes mimics that of a membrane against the initiation of a blister on a bridge. For some membranes in this study, however, progressive peeling did not occur until the pulling force peaked; thereafter, peeling occurred at a lower force (Fig. 4a, 4b, 4c and individual results for Polyguard and Soprema, App. B). This is not unlike what occurs on bridges where, once growth is initiated, blisters seem to expand quite rapidly for a while. For other membranes, peak forces did not develop at all (Fig. 4d, 4e and 4f) near the end of the test (Fig. 4b and 4c). Average values, on the other hand, show a typical adhesion that can be expected. Averages dampen out any of the extreme values during testing and usually provide a reasonable basis of comparison. However, by considering the discussion on blister mechanics, clearly neither maximum nor average values are adequate, because the root cause of all blisters is poor adhesion. Therefore, minimum values are a revealing test result, because a blister simply cannot form unless a membrane is poorly bonded, at least in spots.

With the foregoing in mind, Table 2 was developed from Appendix B to compare the maximum, average, and minimum adhesion values measured in this study. (The values developed from the CRREL-made samples are differentiated from those made by the supplier.) The maximum values in Table 2 were based on the entire loading curve of each strip, whereas the average and minimum values came from the center portion of each testing stage (i.e., from approximately 1 to 2 in. of stage 1 and 3 to 4 in. of stage 2). Using only the center portion avoided effects caused by the start-up or end of each test. As can be seen, the Polyguard and Soprema membranes have the best adhesion values when either maximum or average values are considered. However, the situation changes when minimum values are considered.

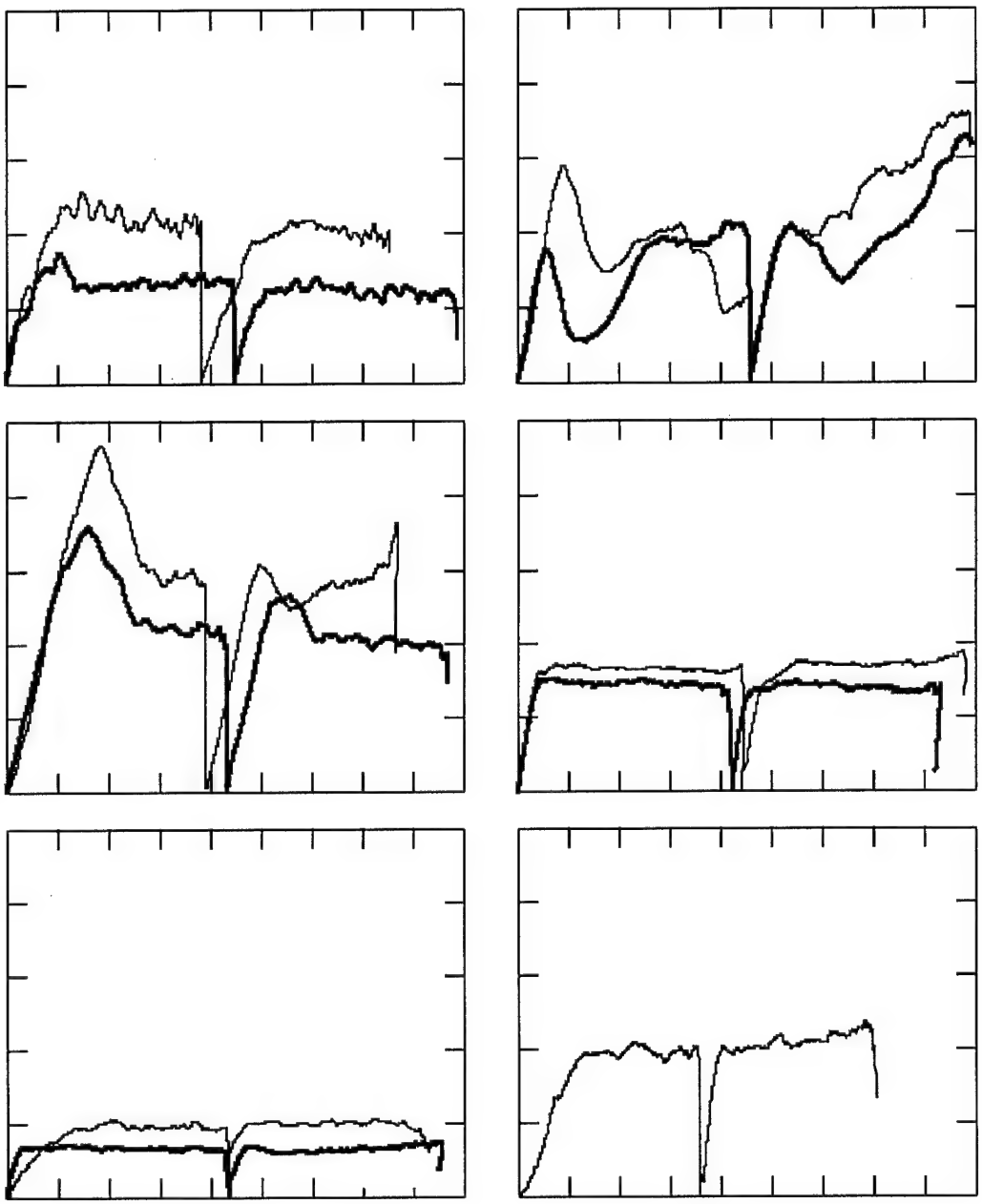


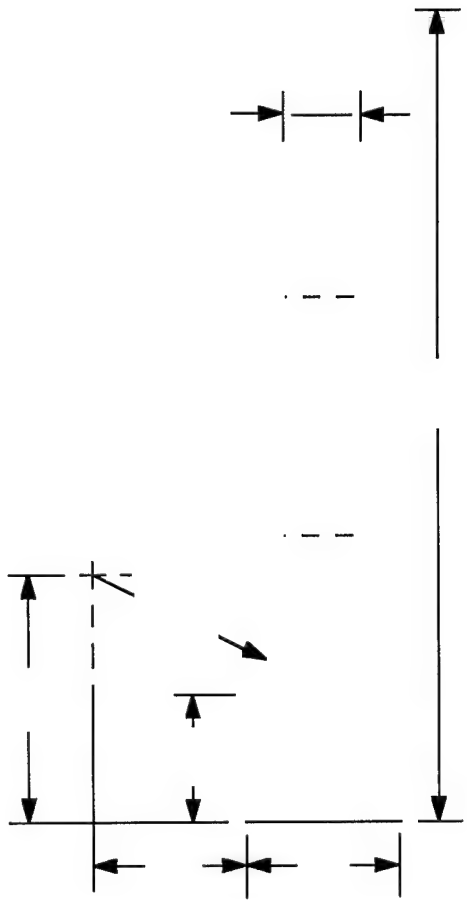
Figure 4. Adhesion test results. Each curve is the average of up to 15 test strips. Surprisingly, the CRREL samples consistently developed high overall, but low individual, adhesion values (Fig. 4 vs. App. B).

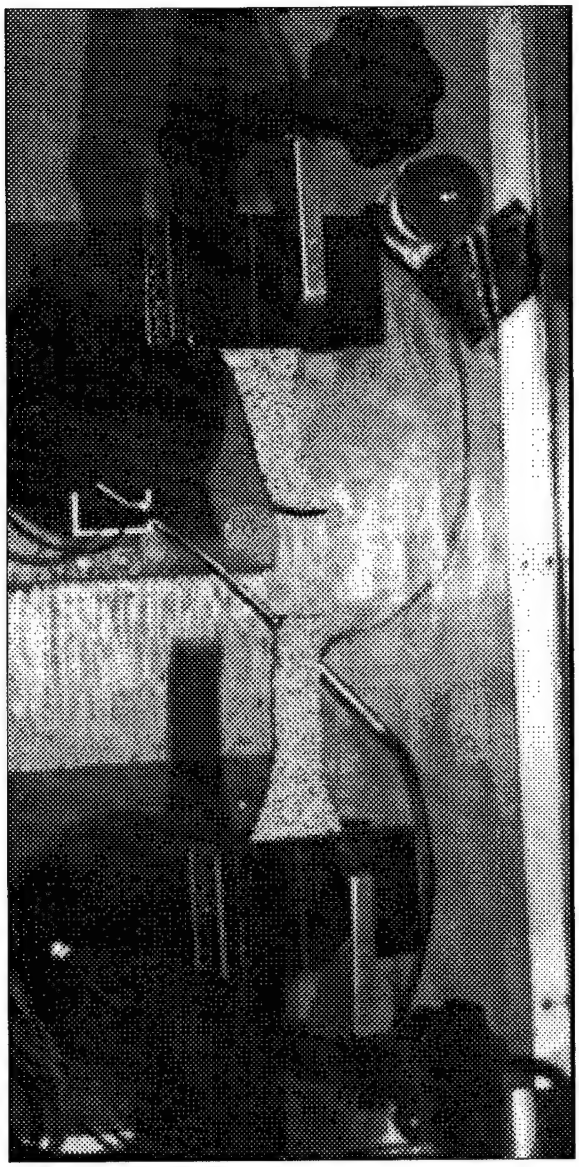
Here, the Protecto Wrap and W.R. Grace membranes become the membranes with the least potential problems. They exhibit moderate, but very uniform, adhesion values with little indication of weak spots (Fig. 4a and 4d). Interestingly, the Protecto Wrap membrane seemed the least influenced by the source of the samples for testing. This uniformity suggests that this membrane would provide a consistent adhesion in the field from job to job and contractor to contractor.

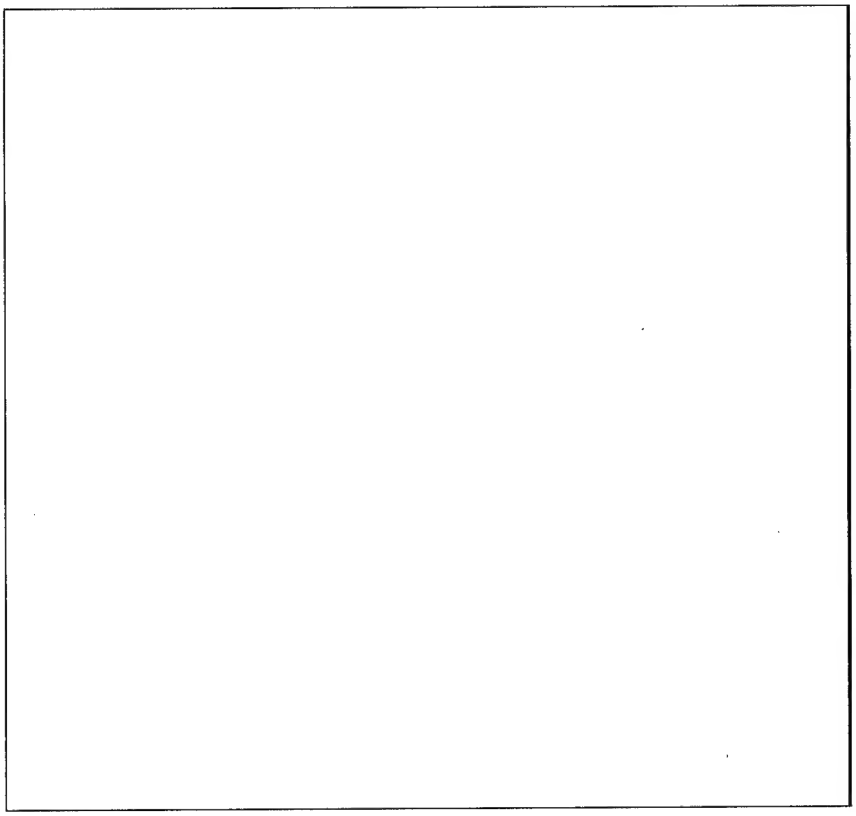
TENSILE STRENGTH AND ELONGATION

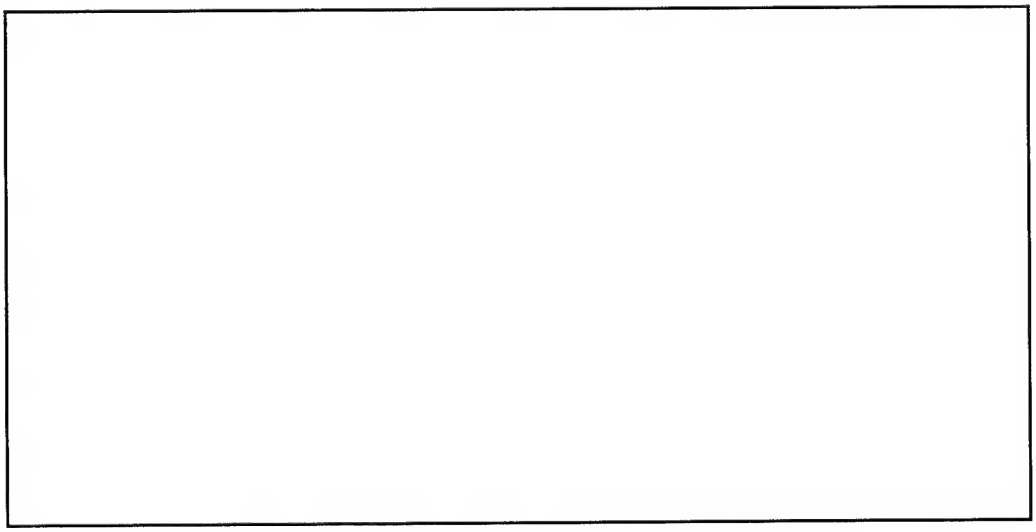
Waterproofing membranes must be able to span active cracks in a deck, especially at low temperatures, when cracks widen most. To do this, a mem-

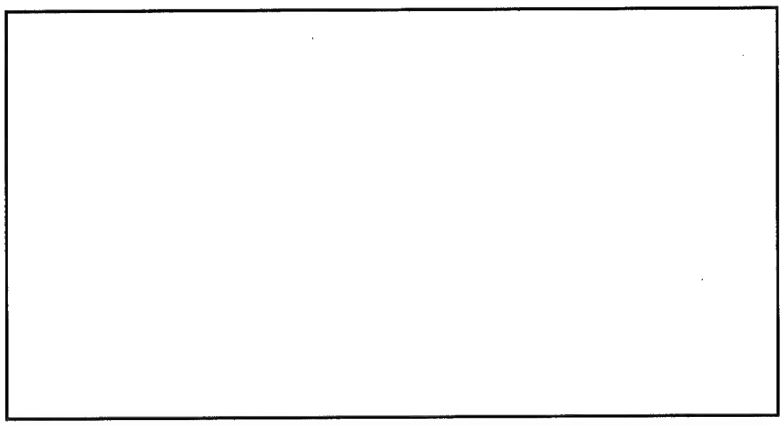
peratures, including below freezing.

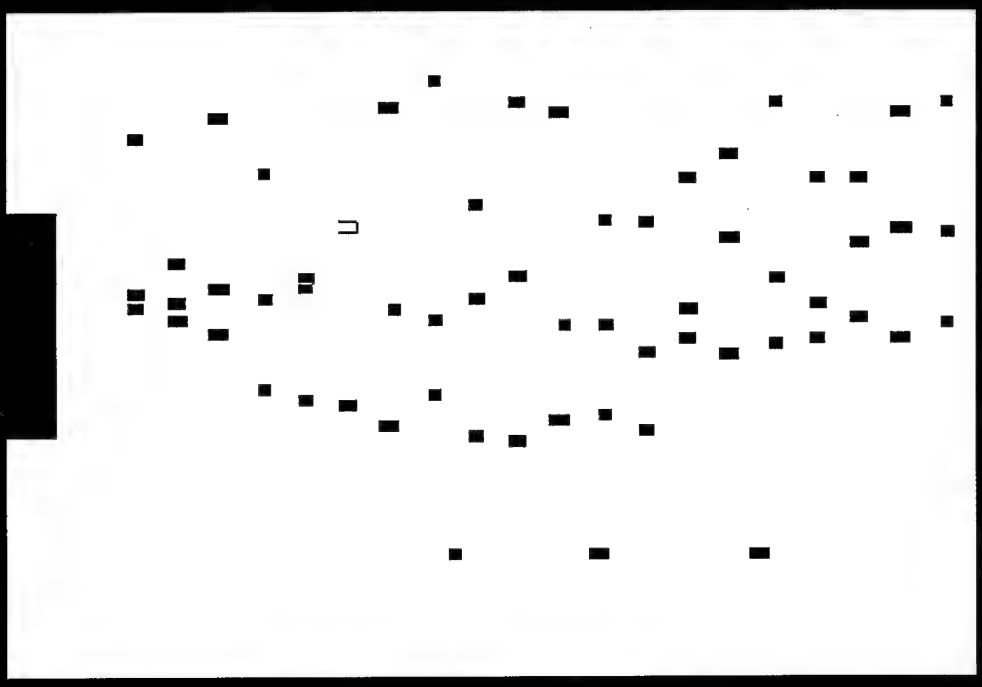


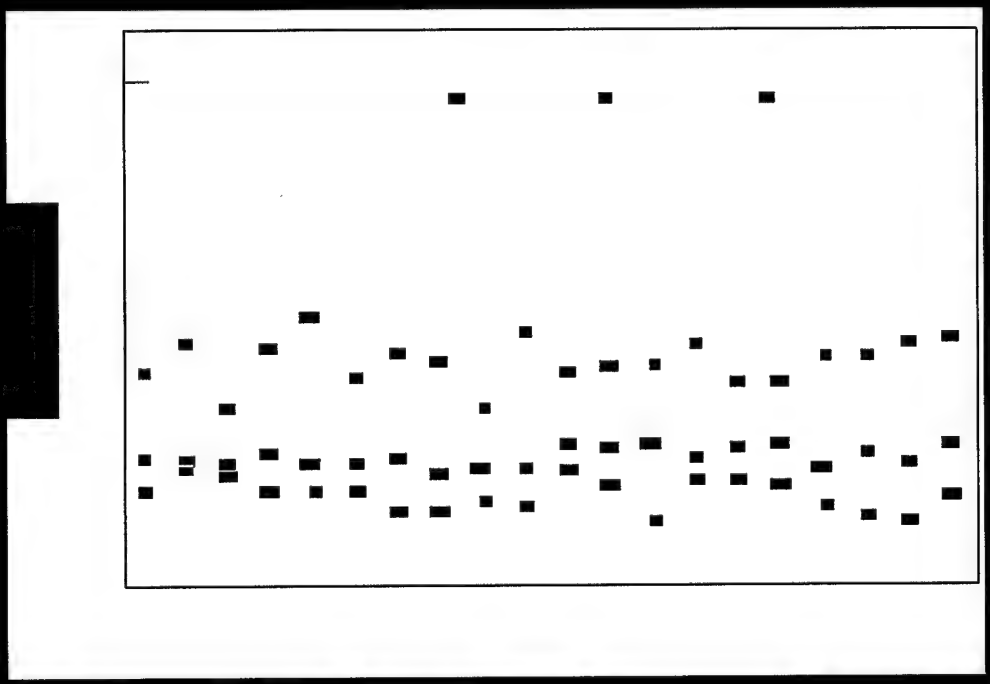


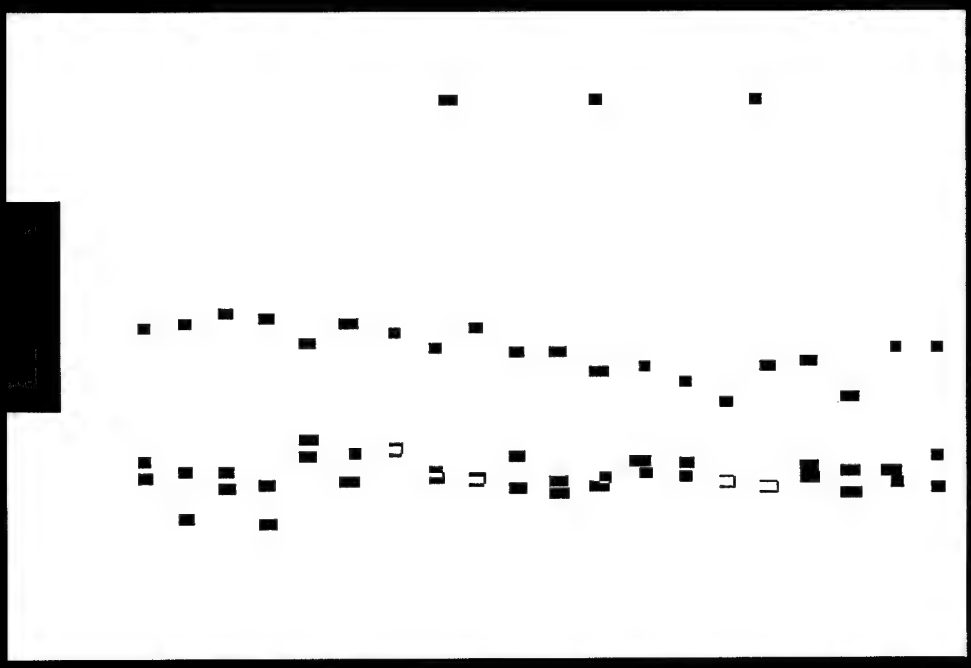


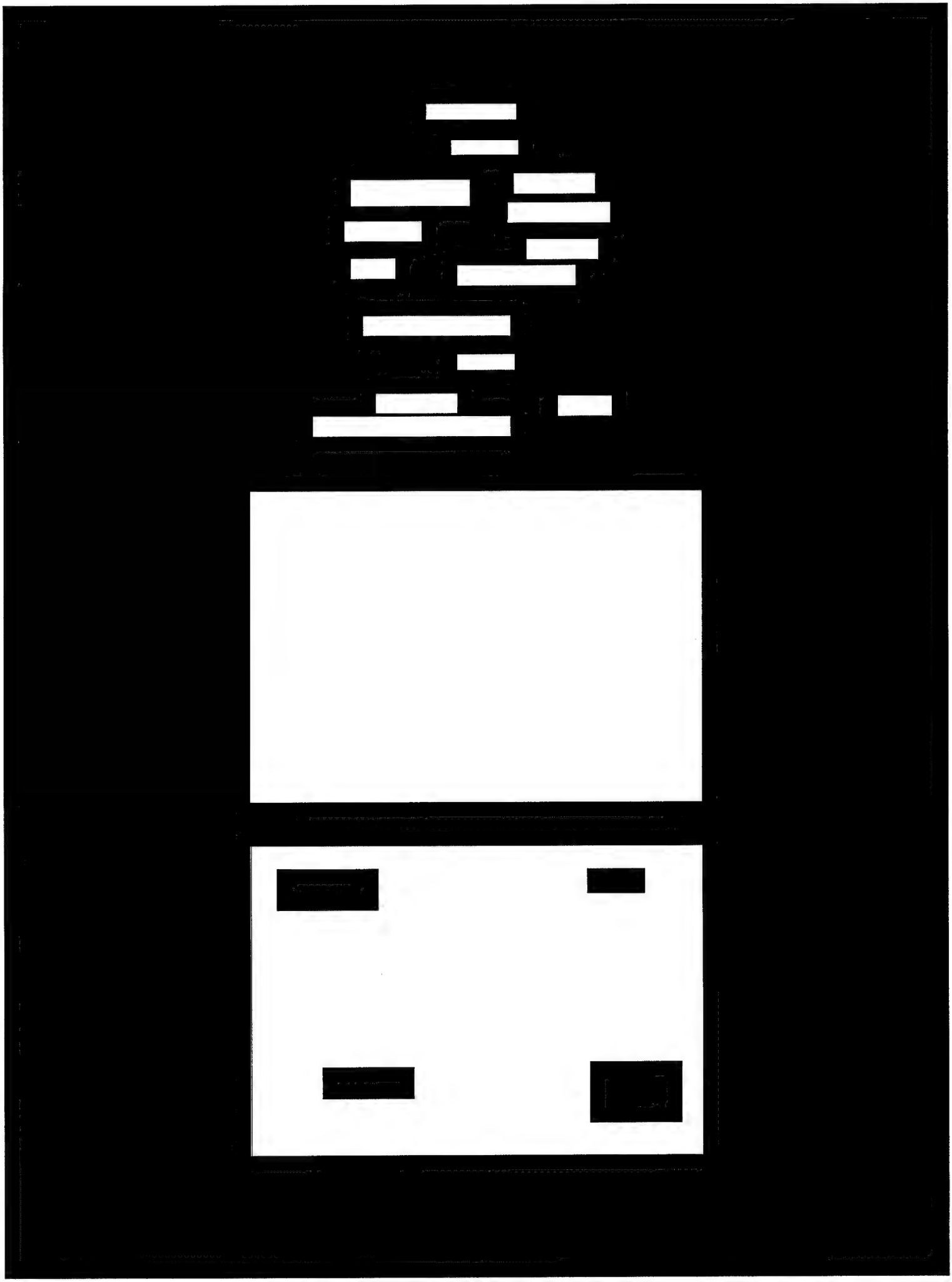


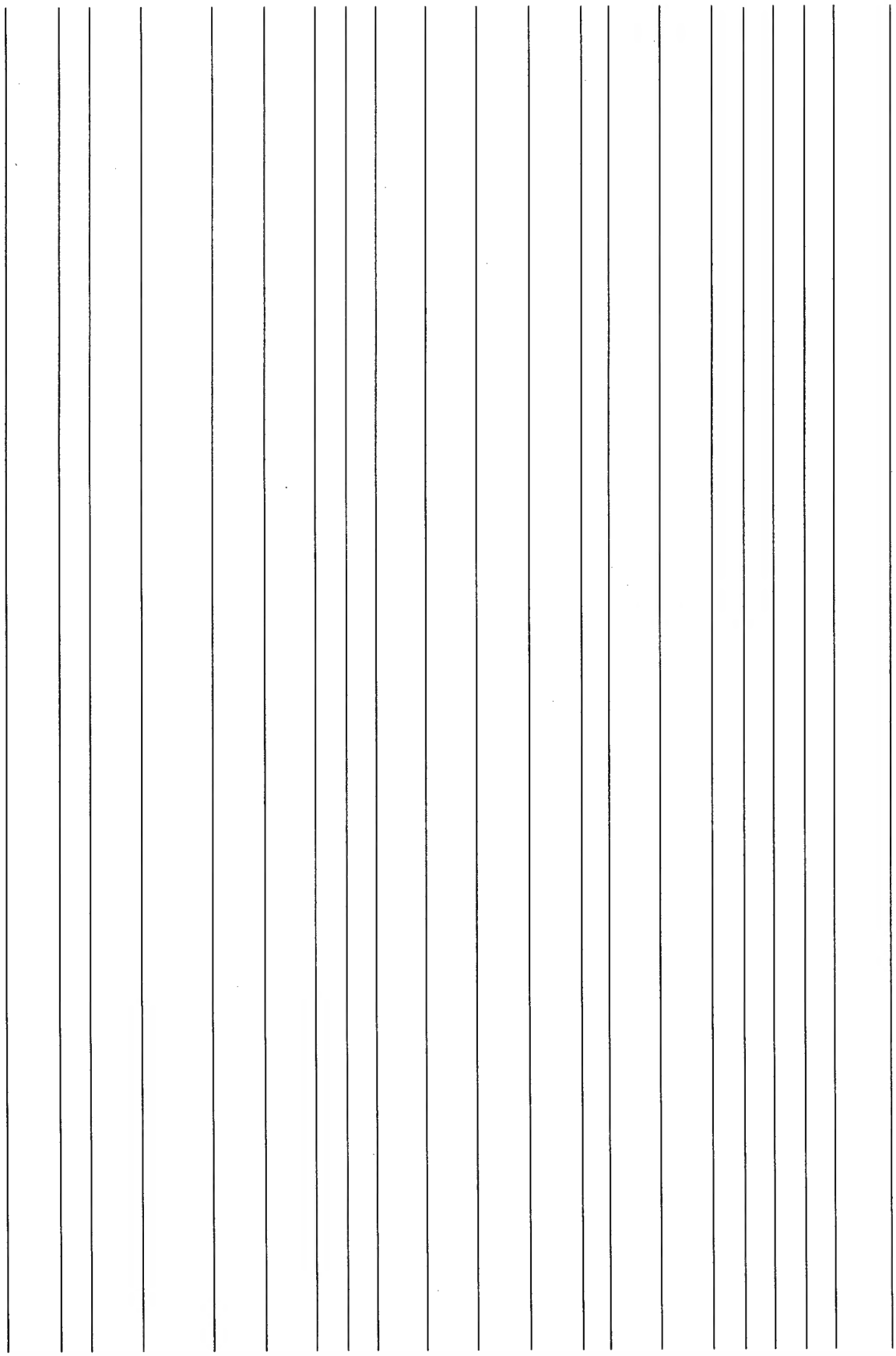


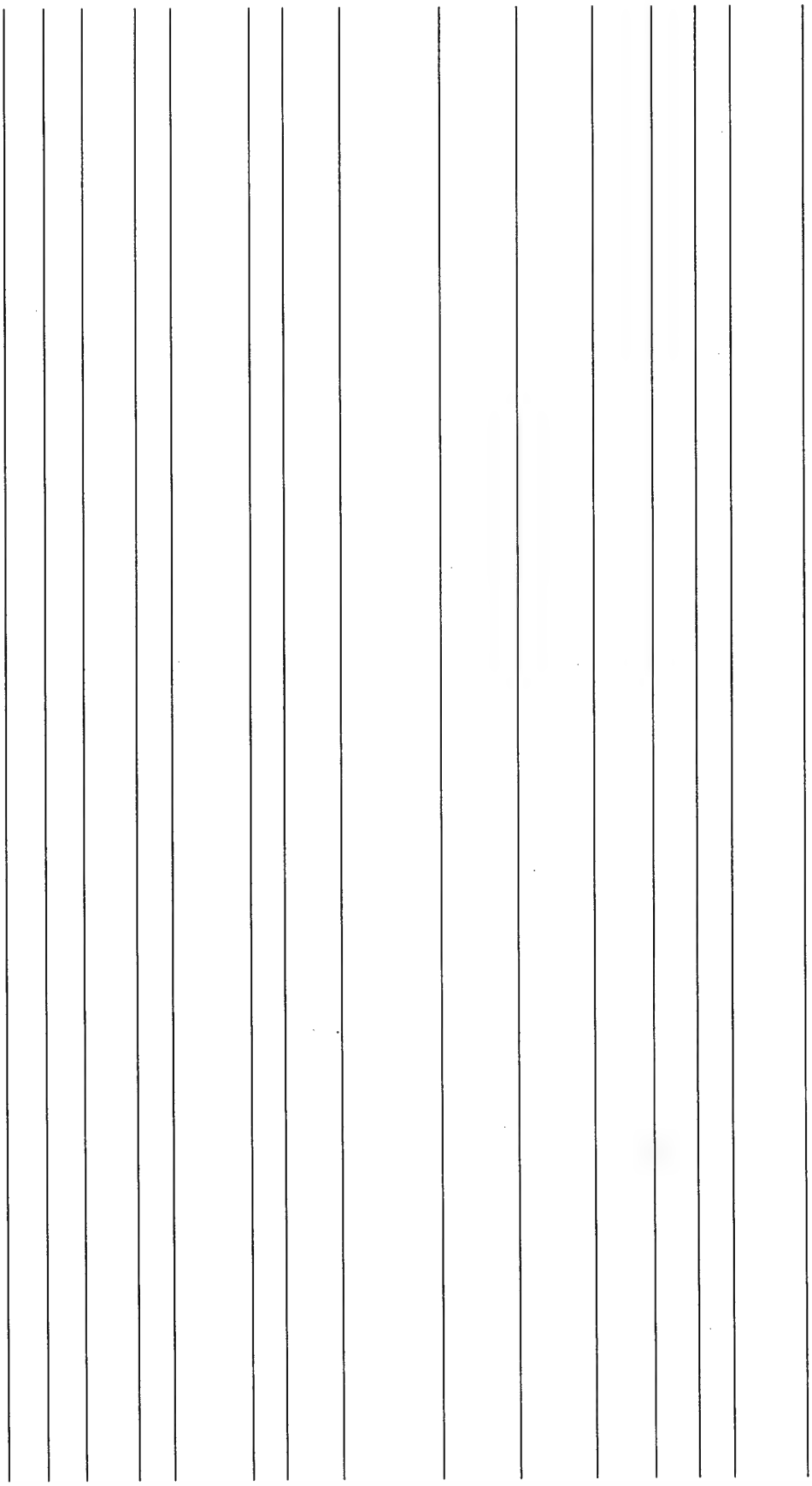


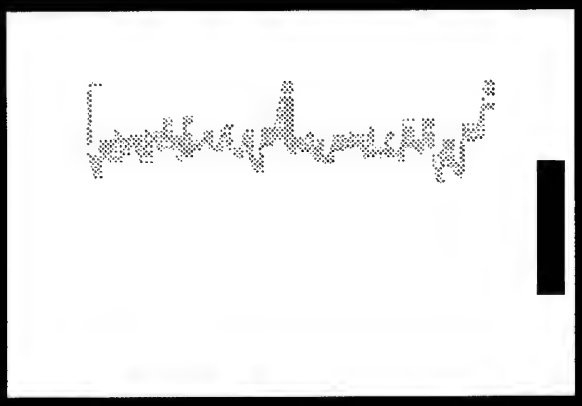


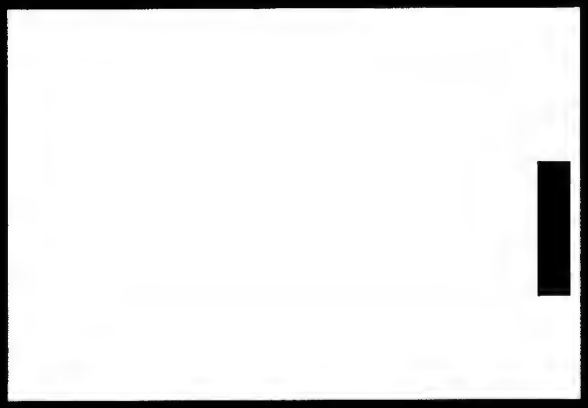


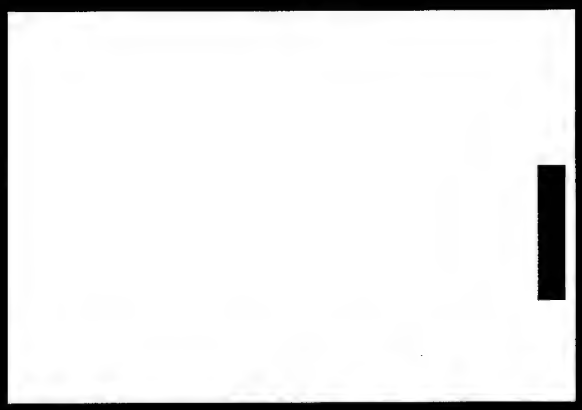


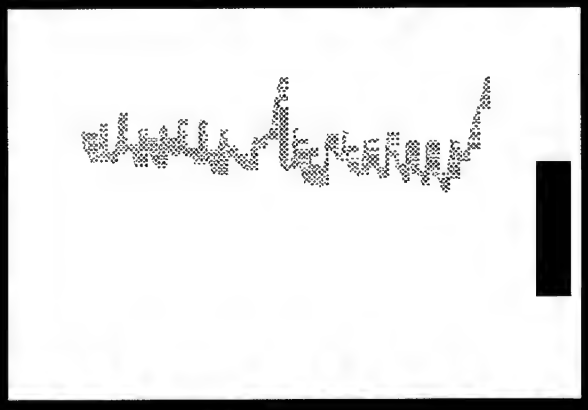


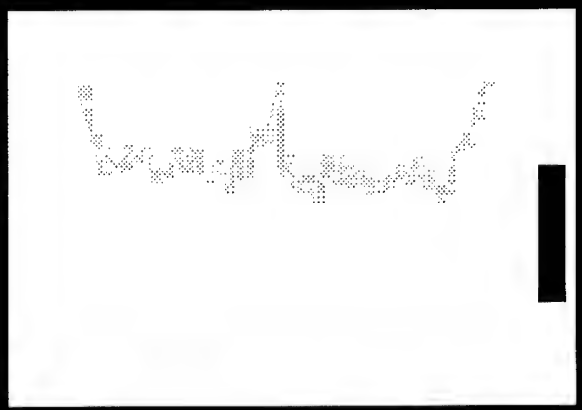


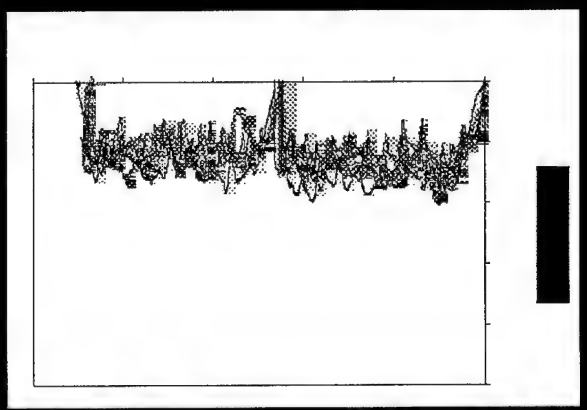


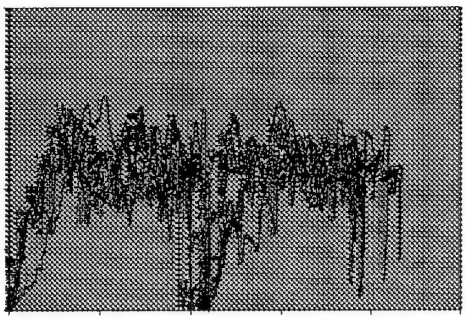


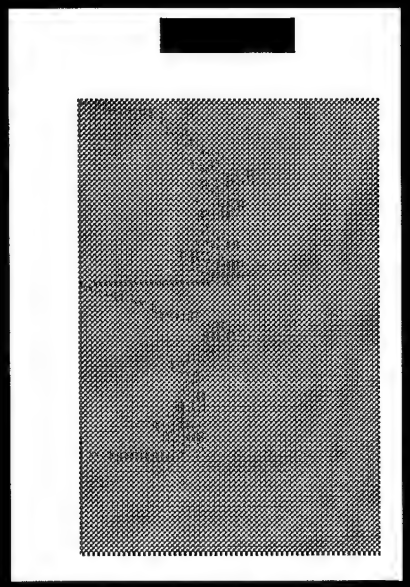


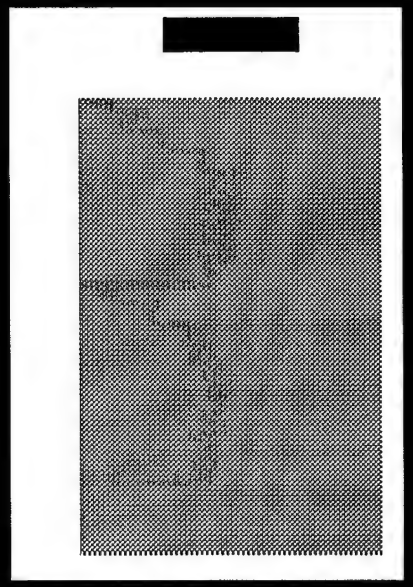


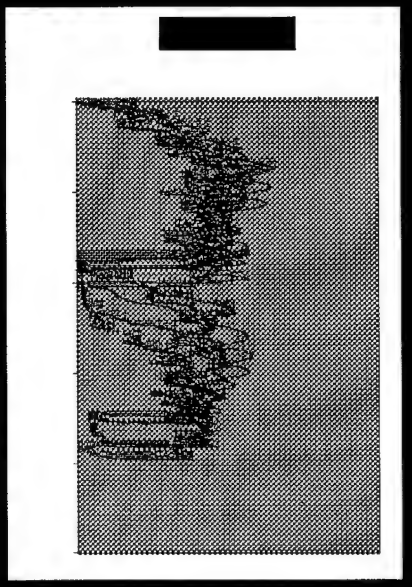


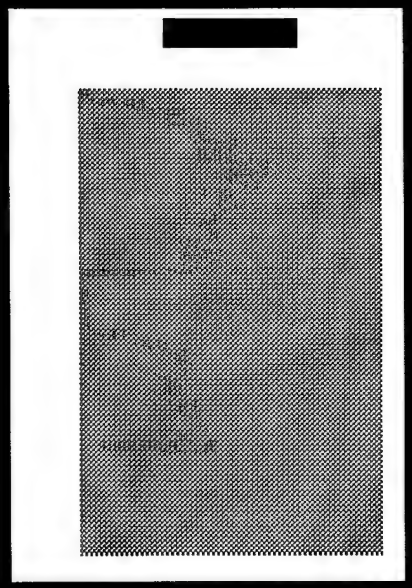


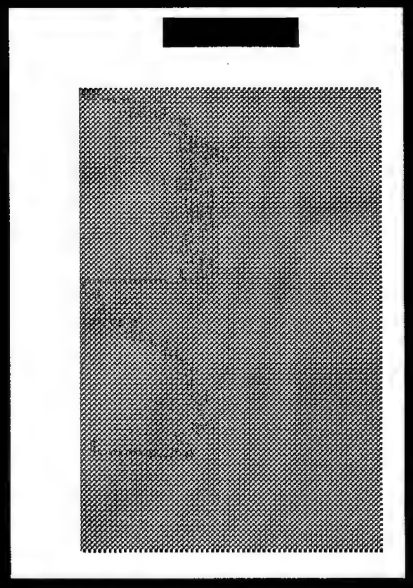


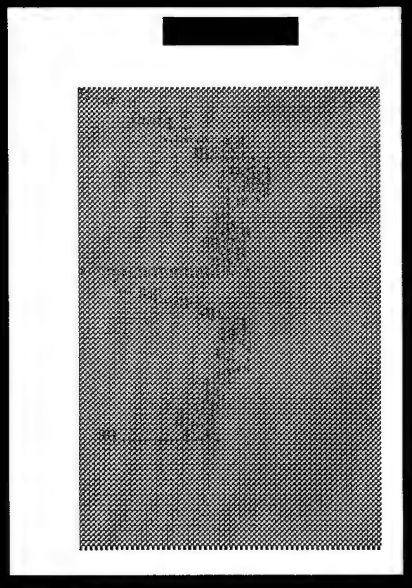


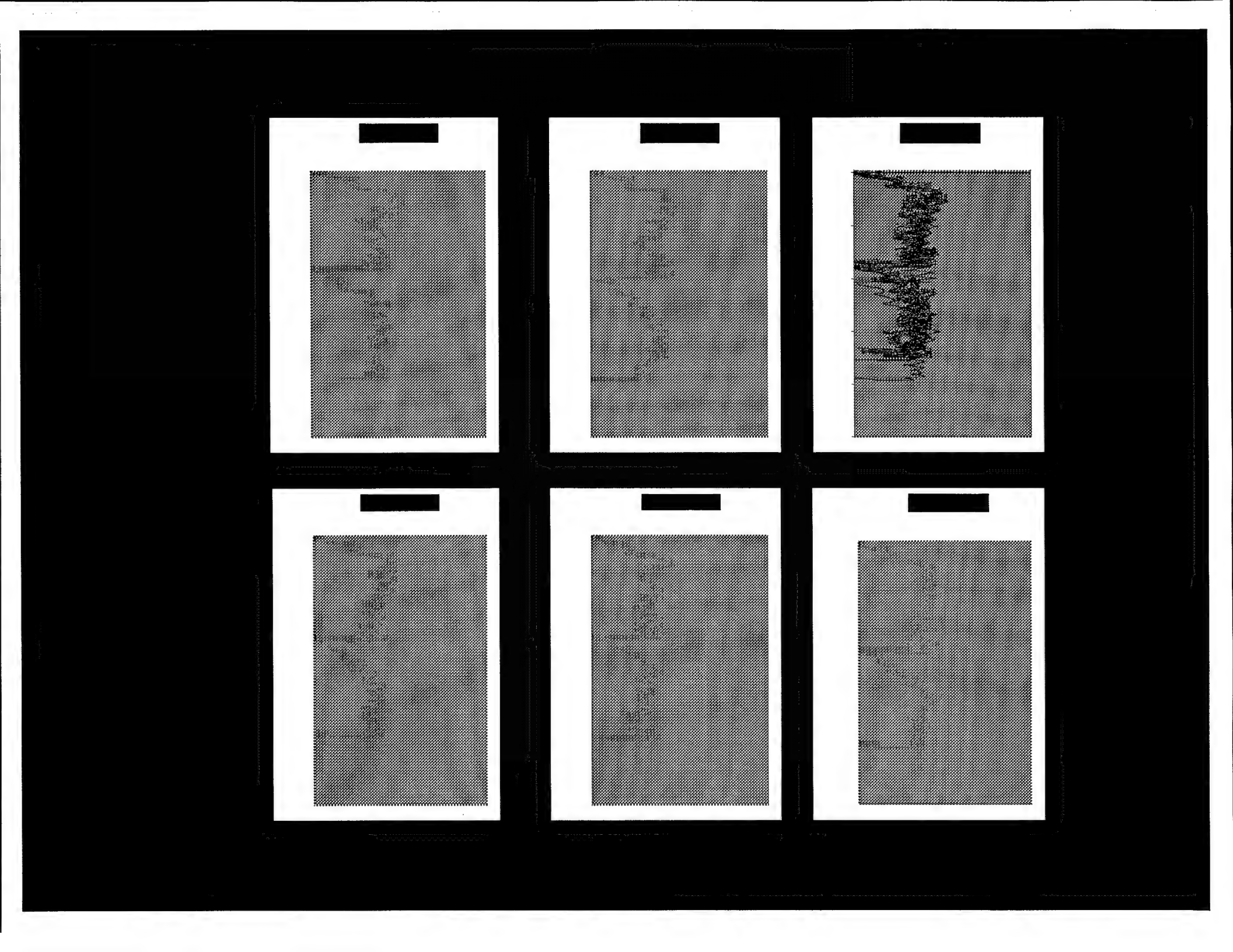


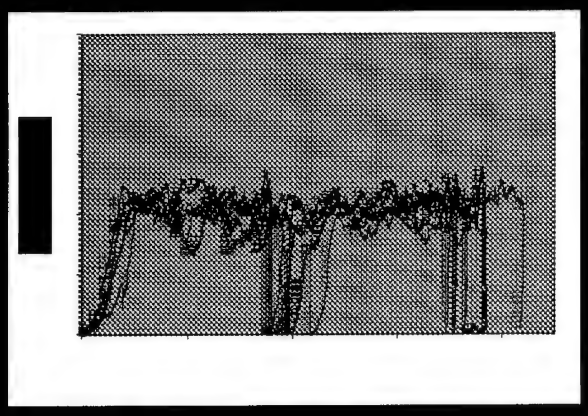


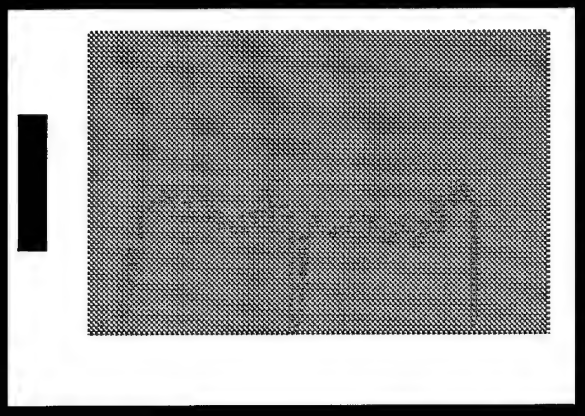


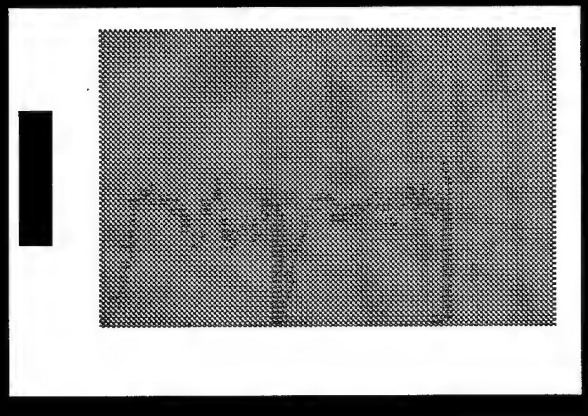


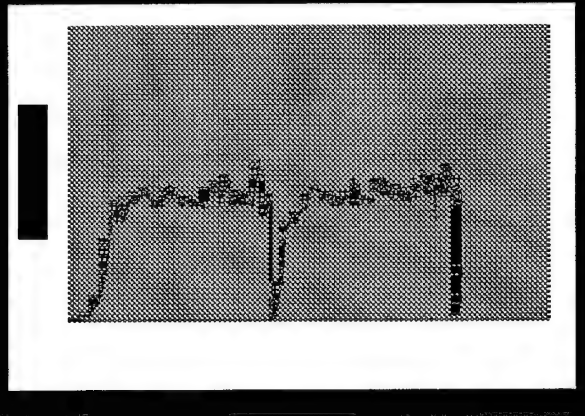


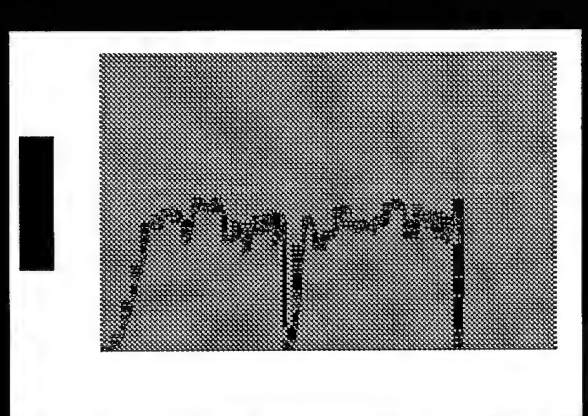


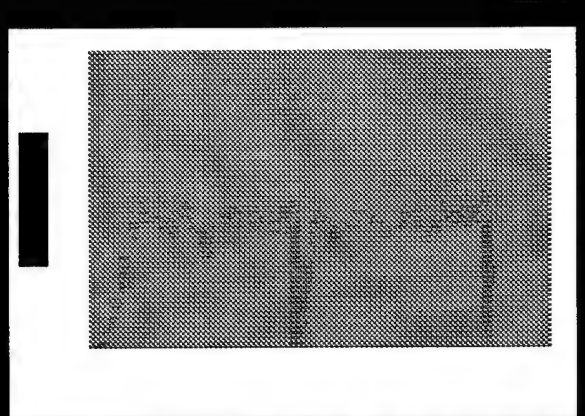


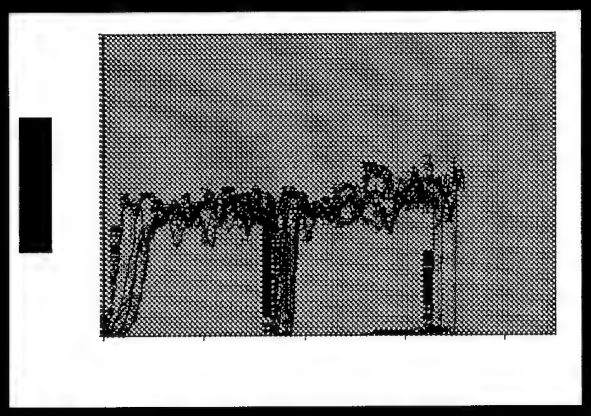


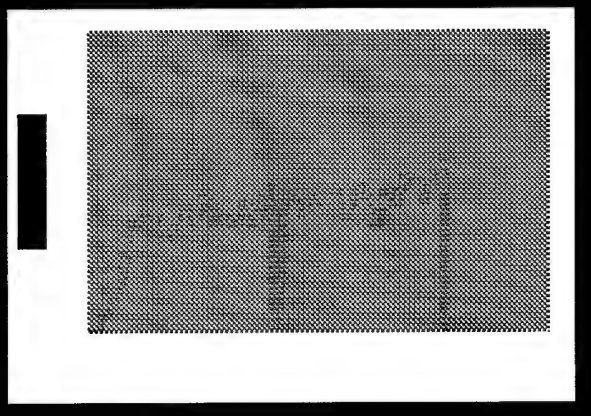


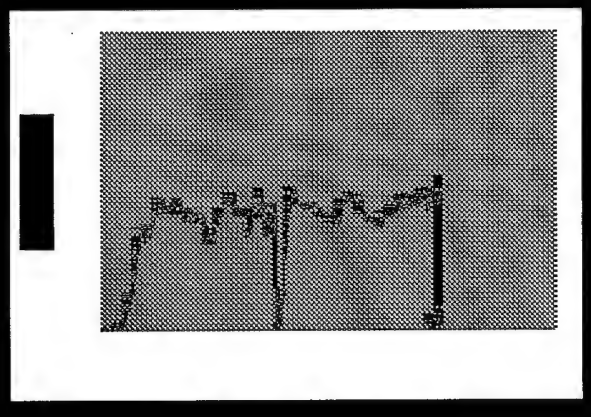


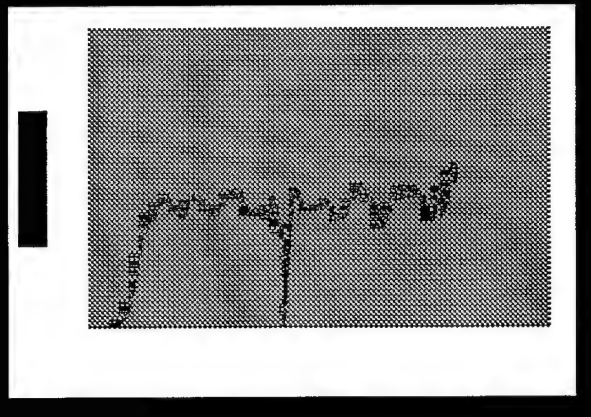


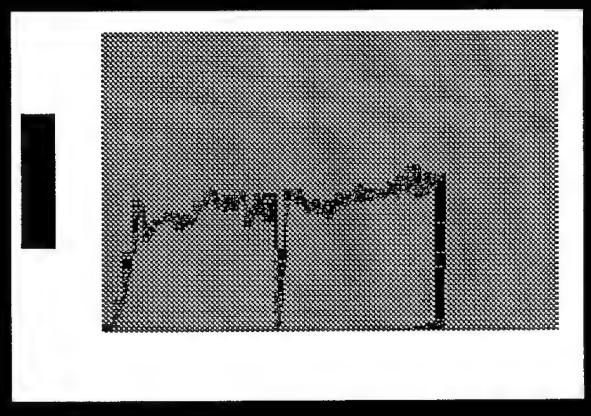


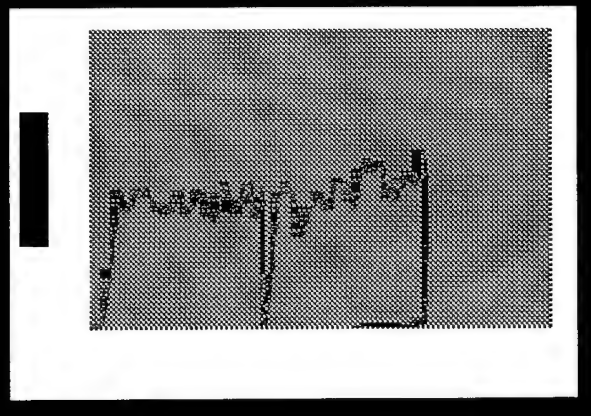


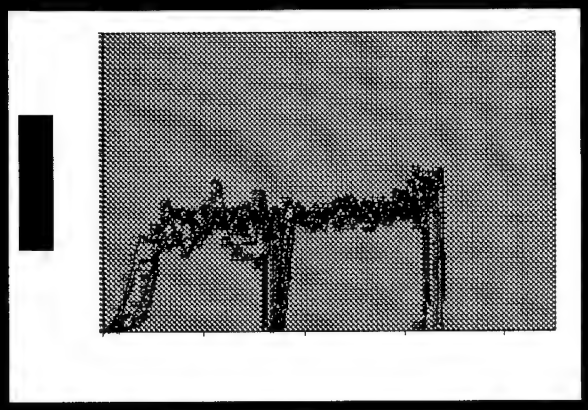


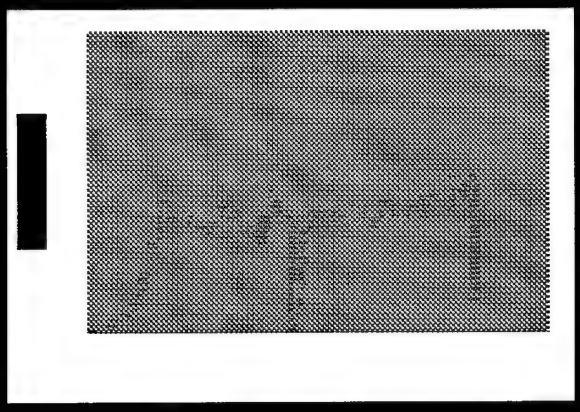


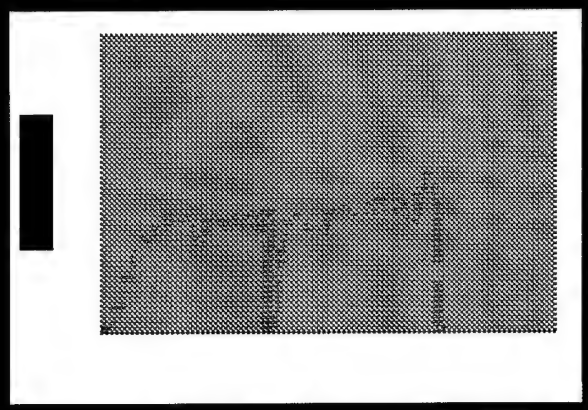


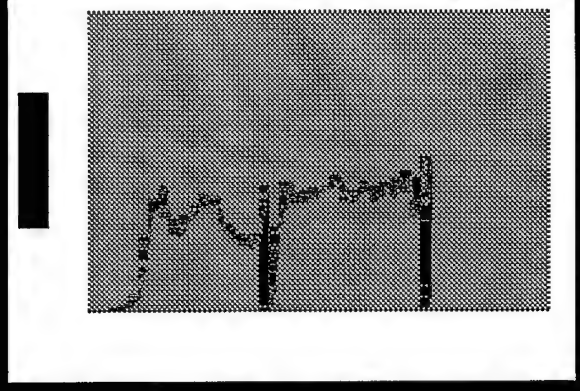


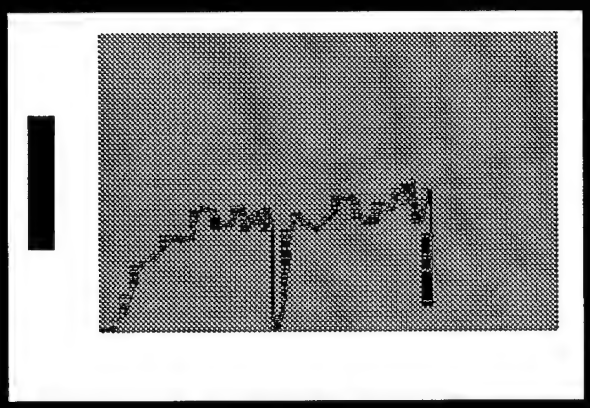


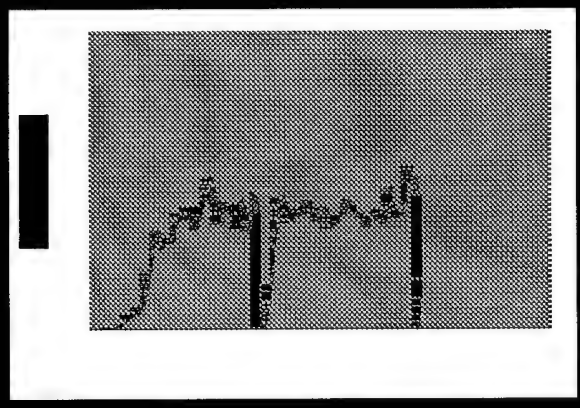


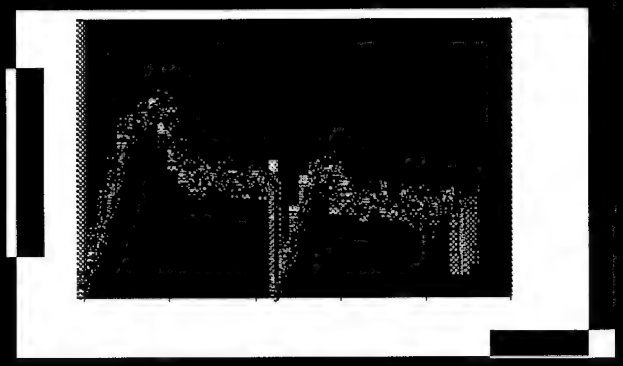


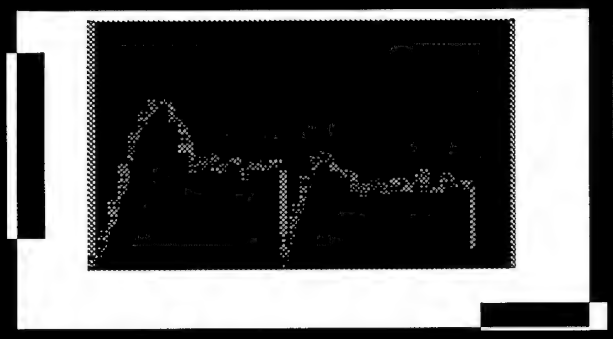


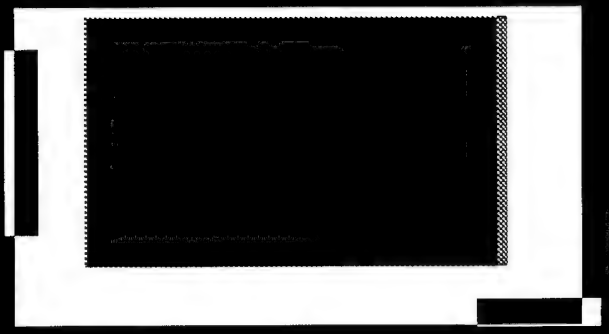


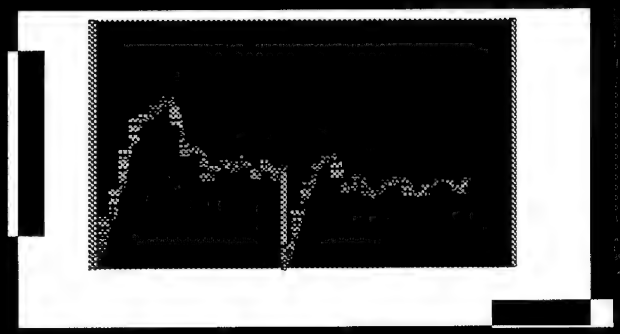


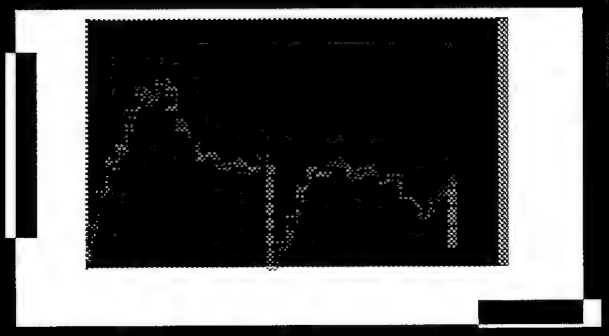


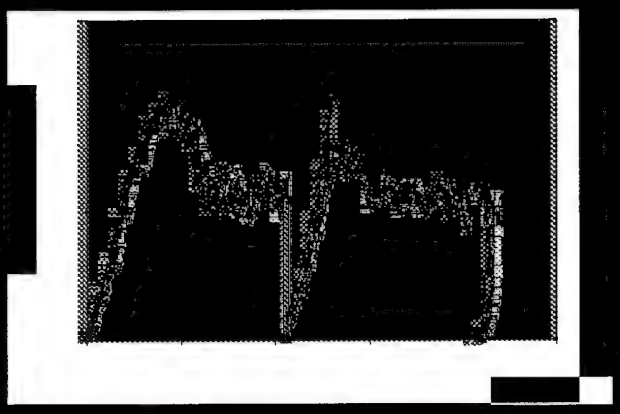


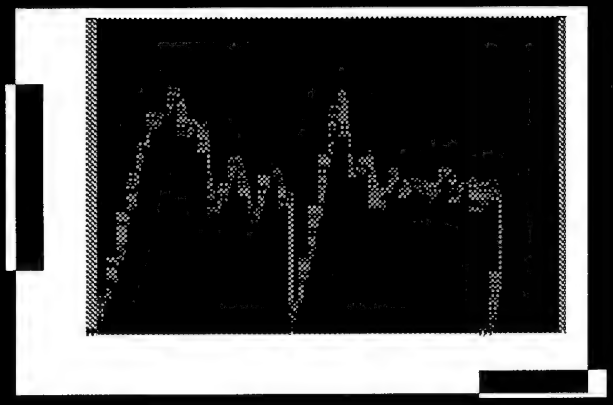


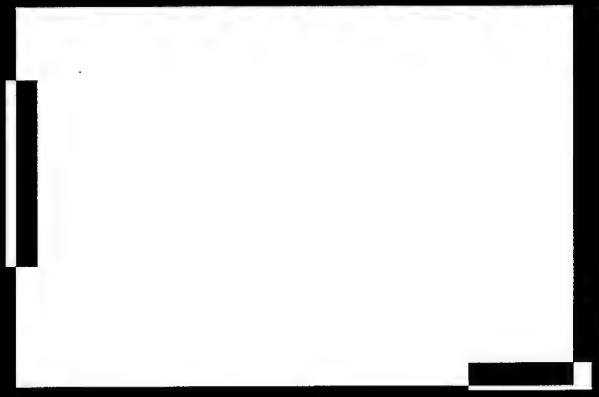


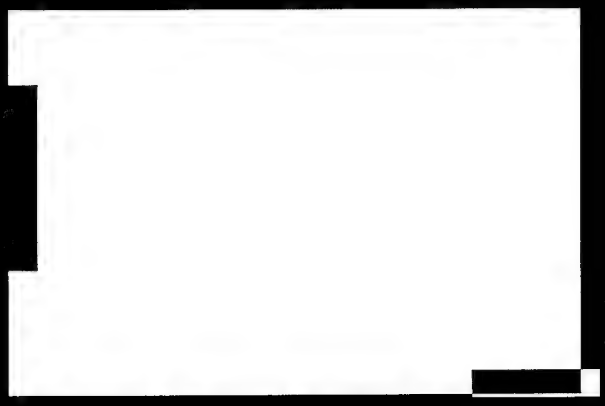


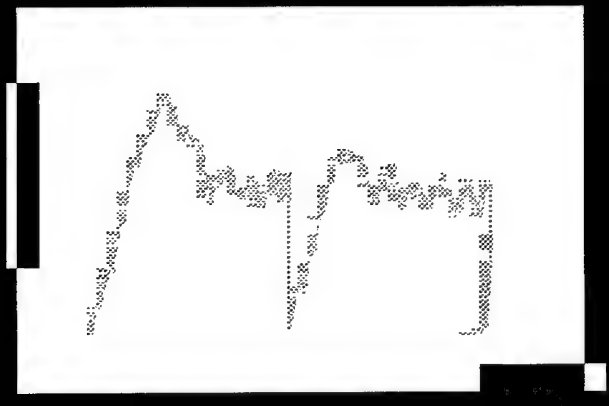


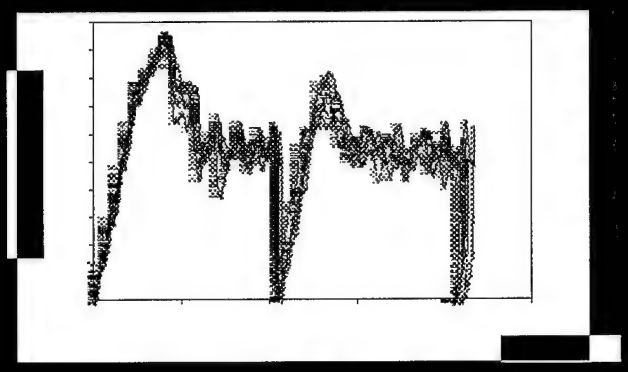


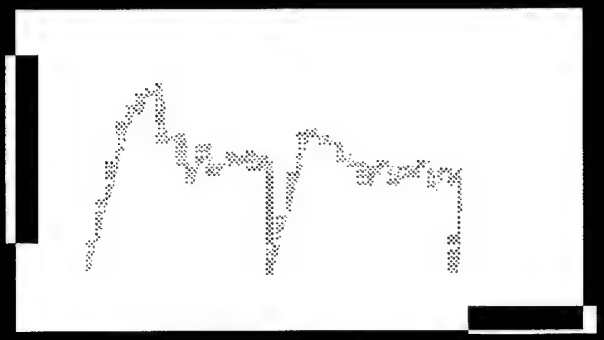


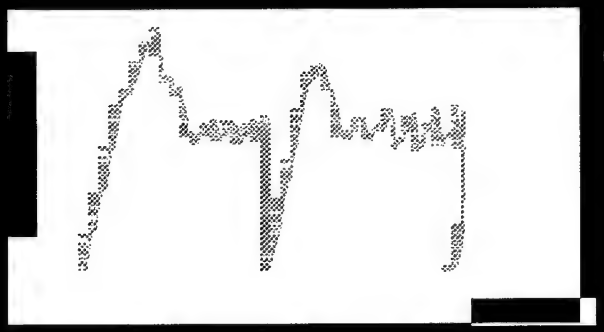


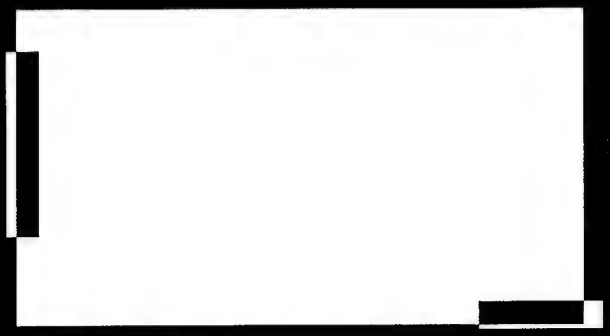


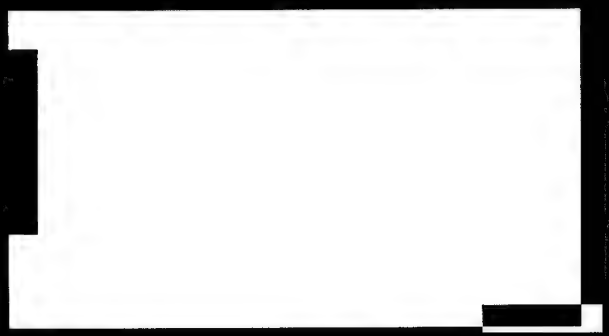


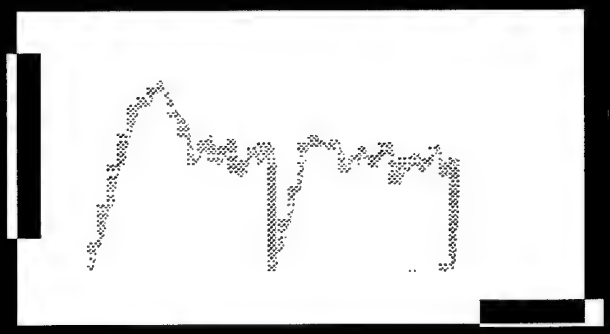


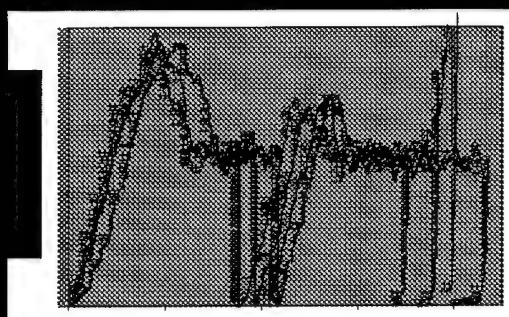


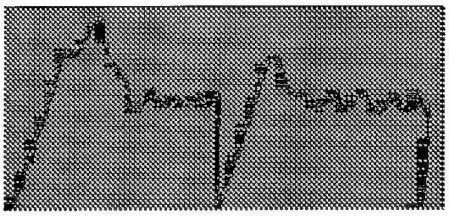


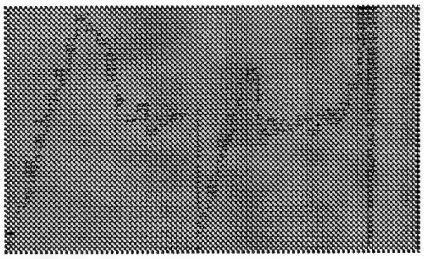


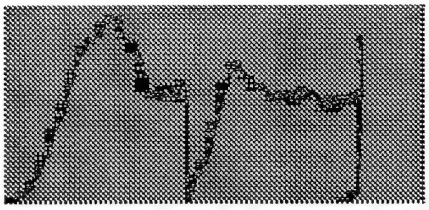


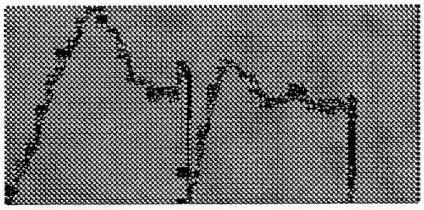


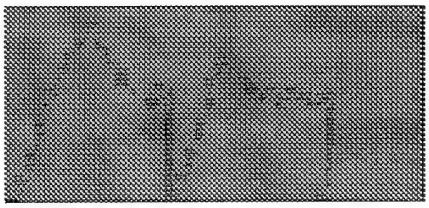


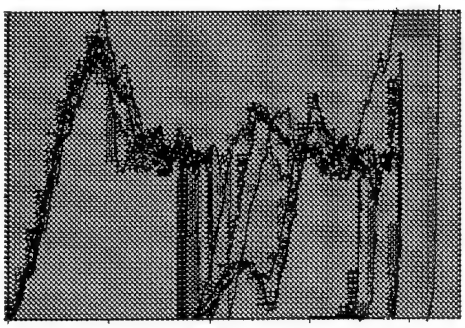


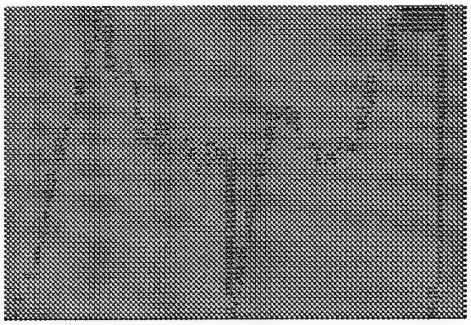


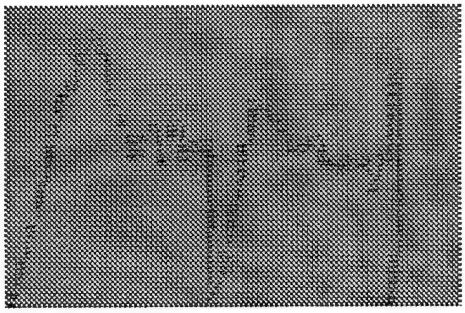


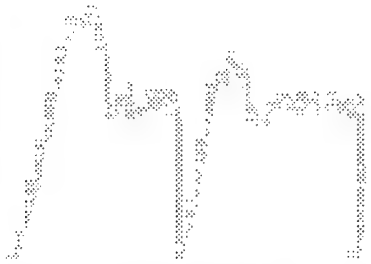


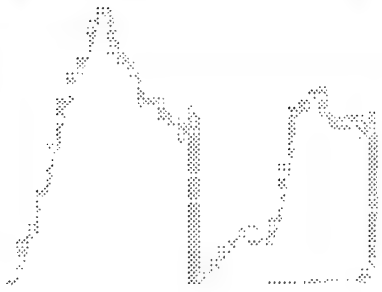


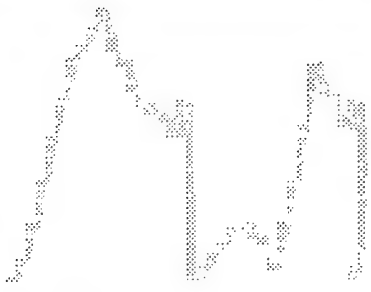


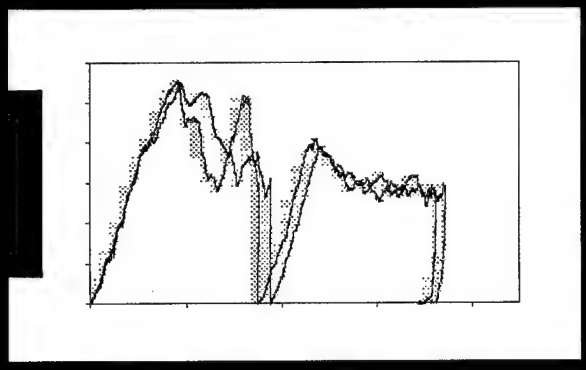


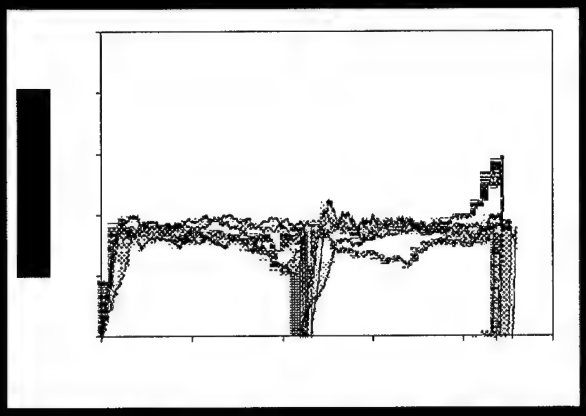


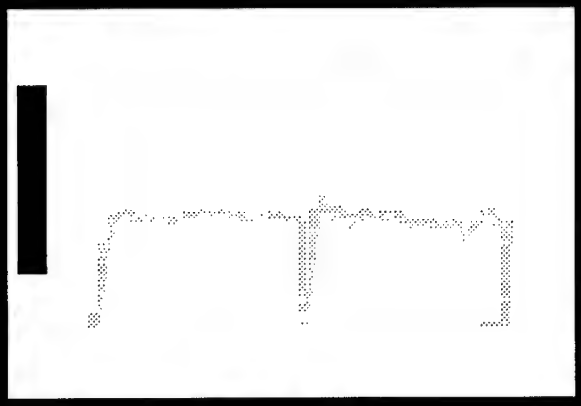


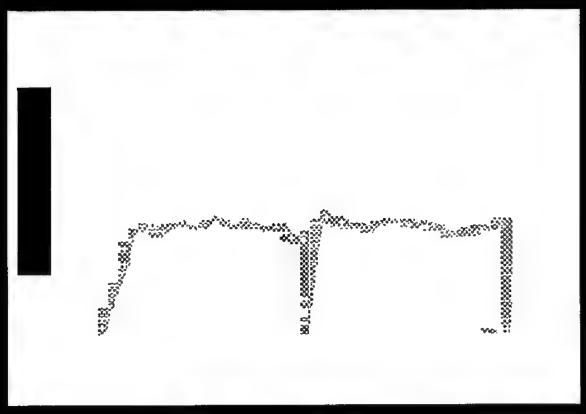


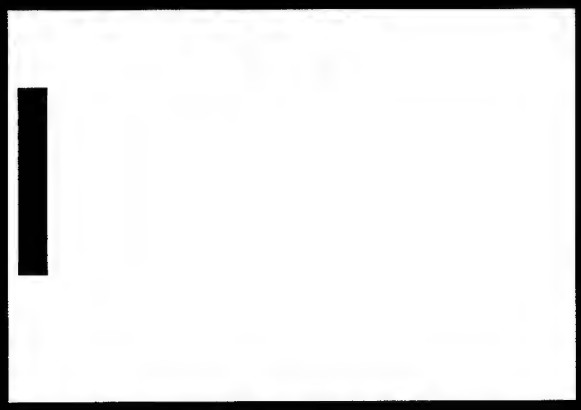


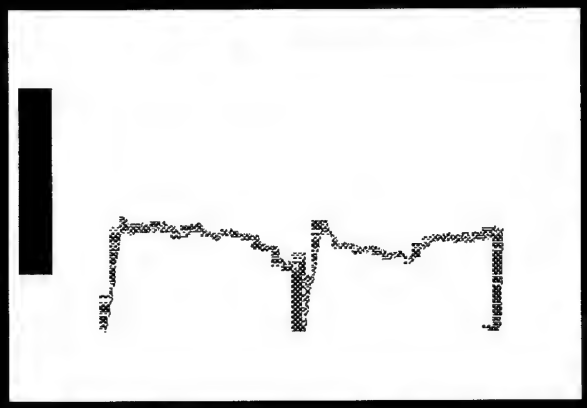


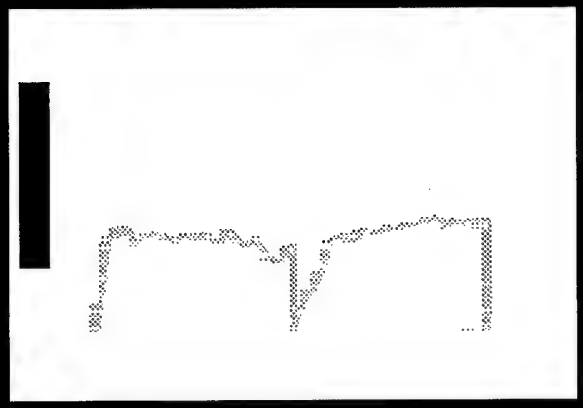


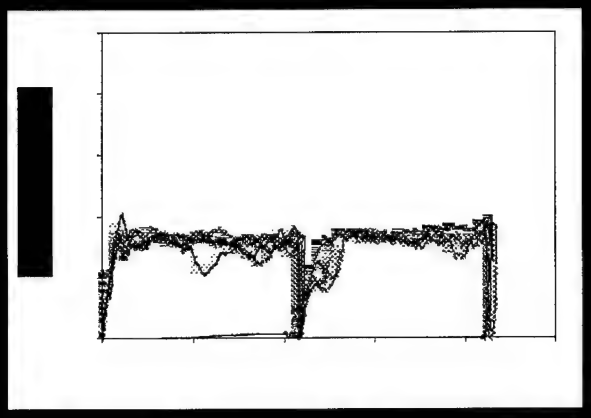


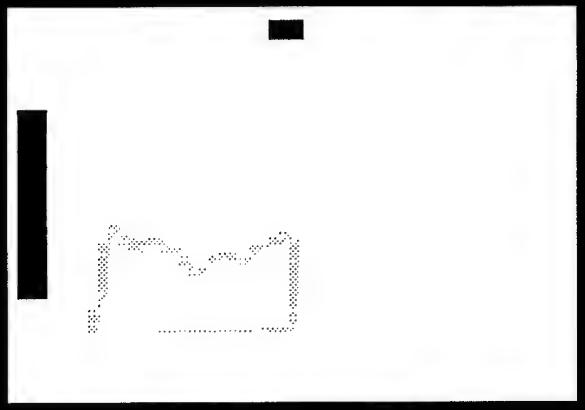


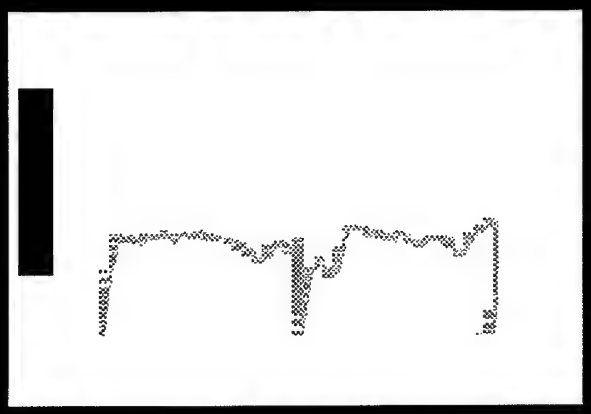


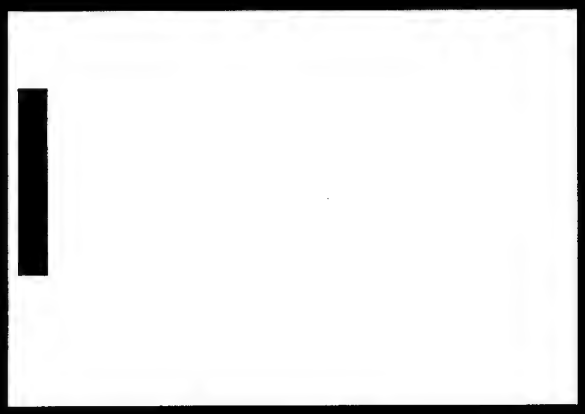


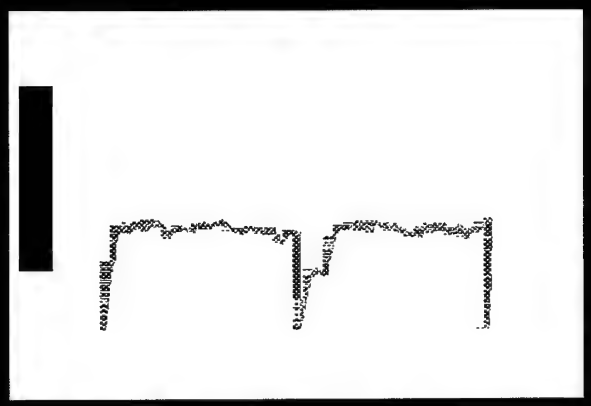


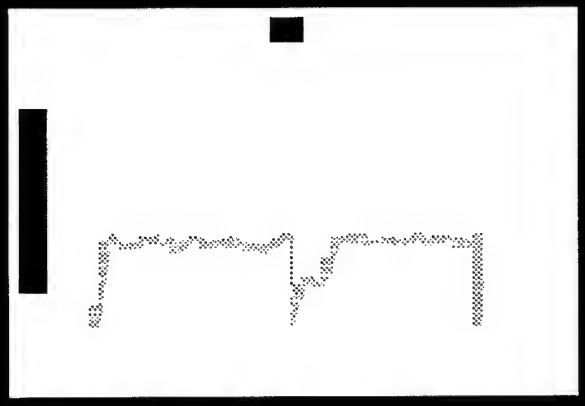


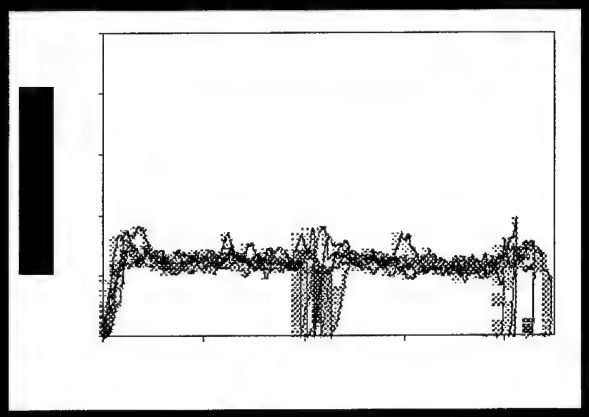


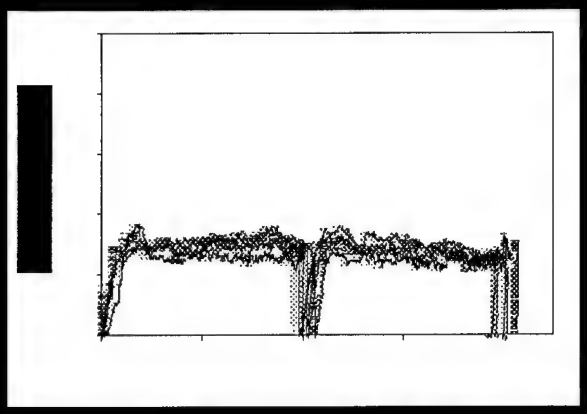


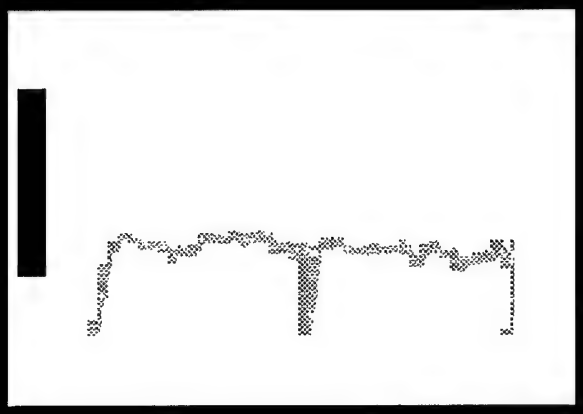


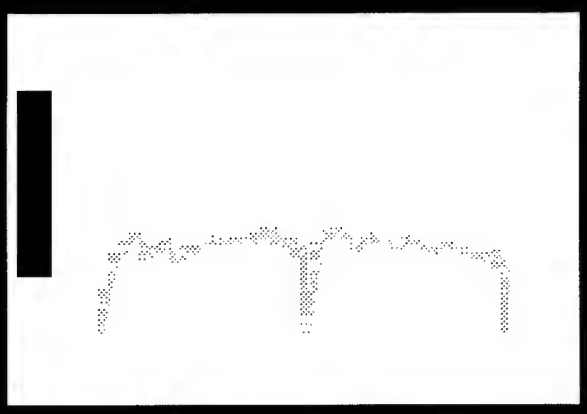


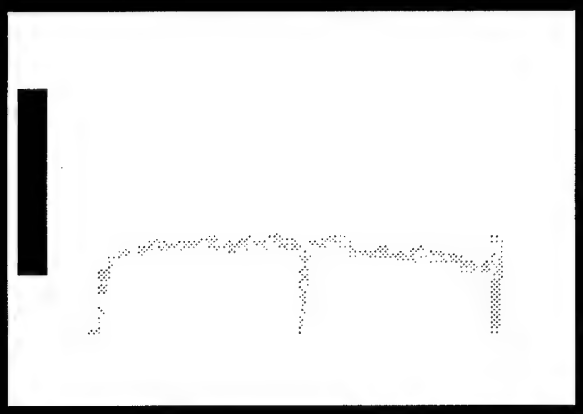


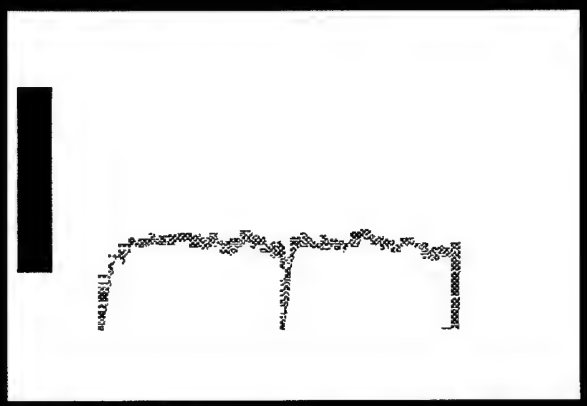


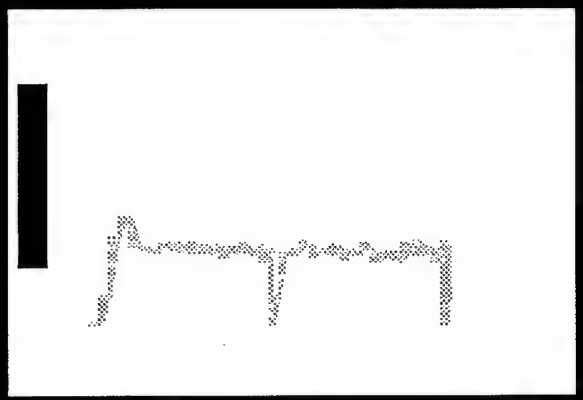


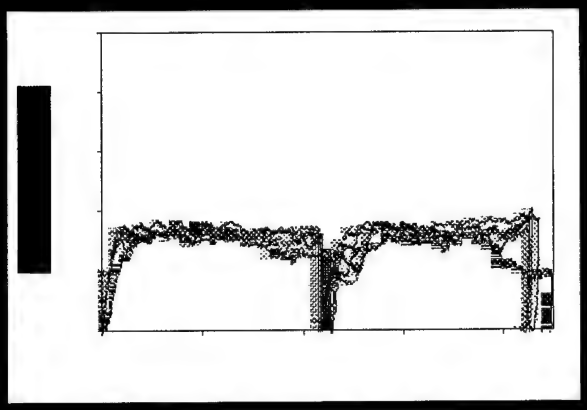


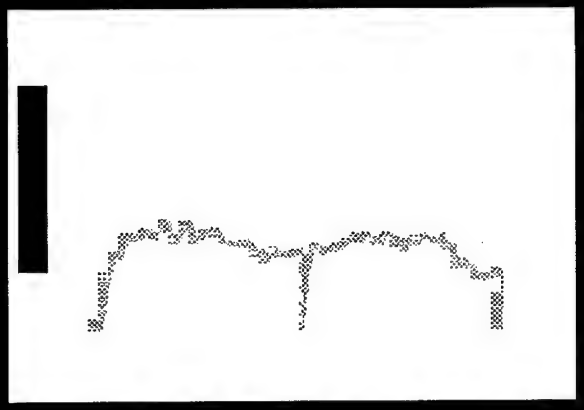


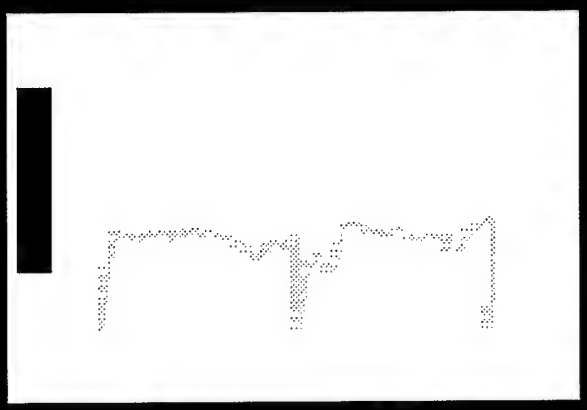


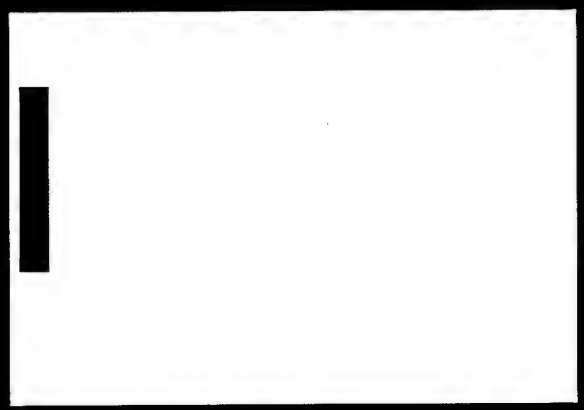


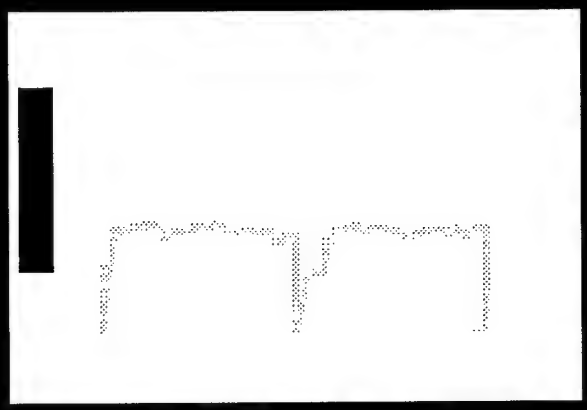


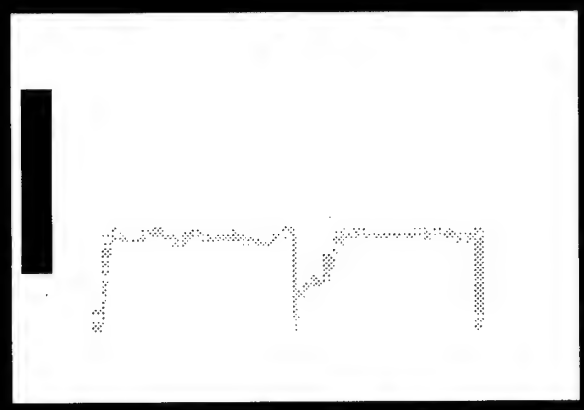


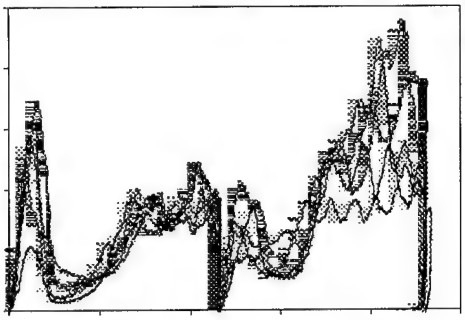


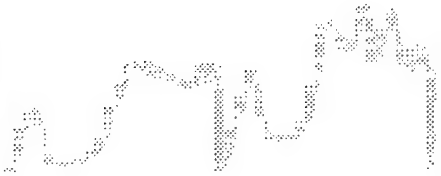


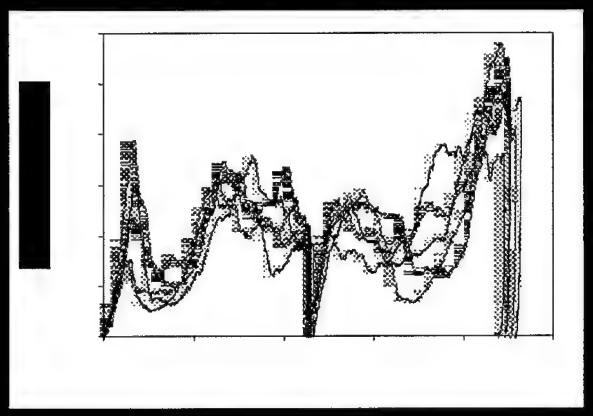


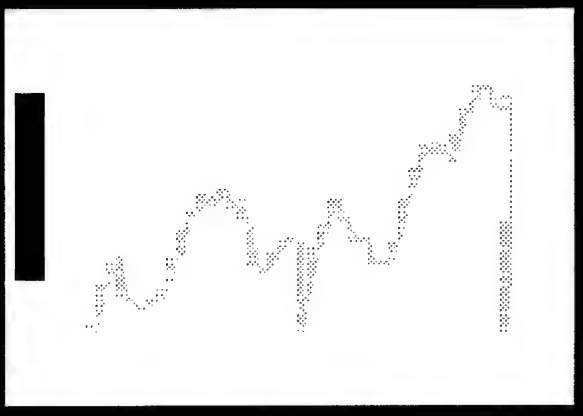


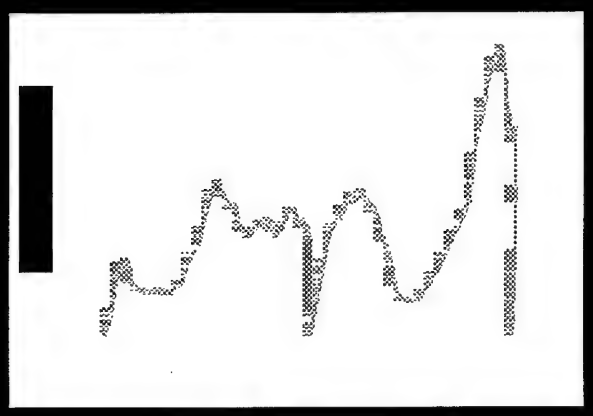


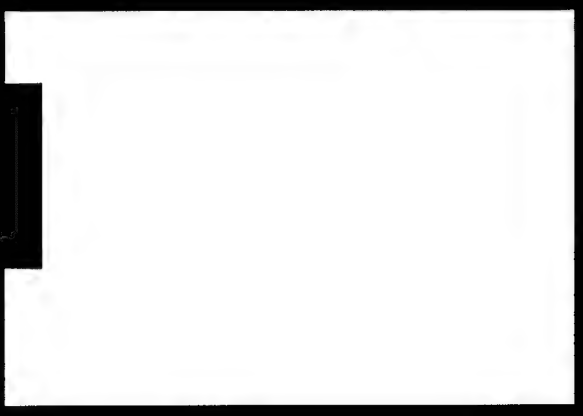


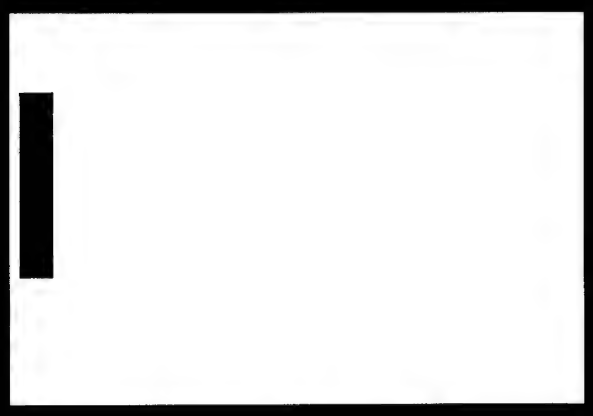


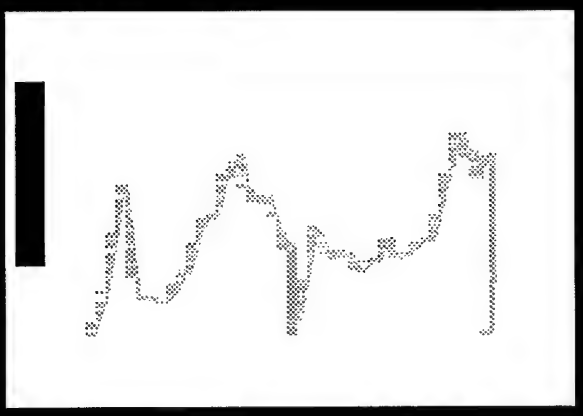


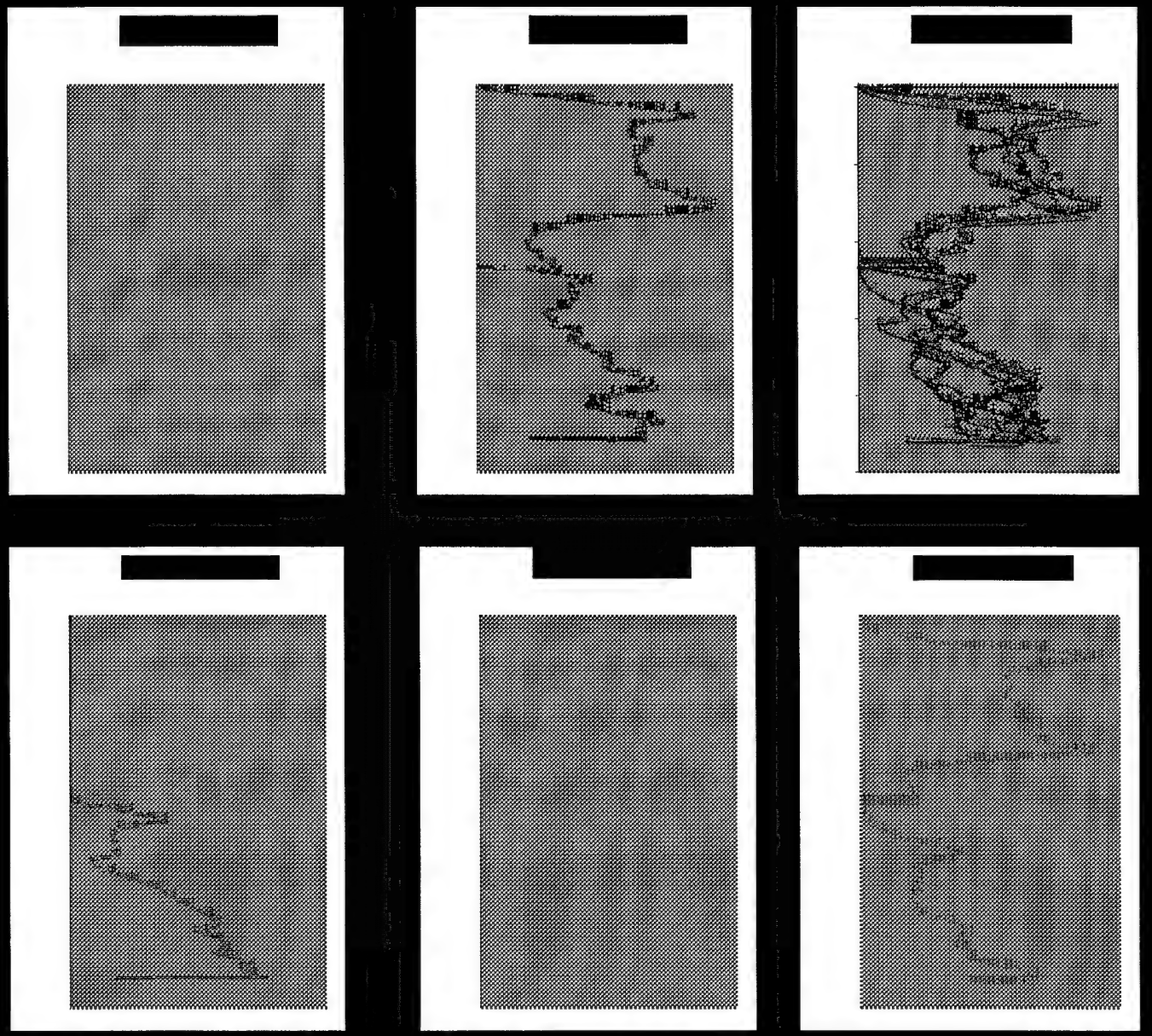


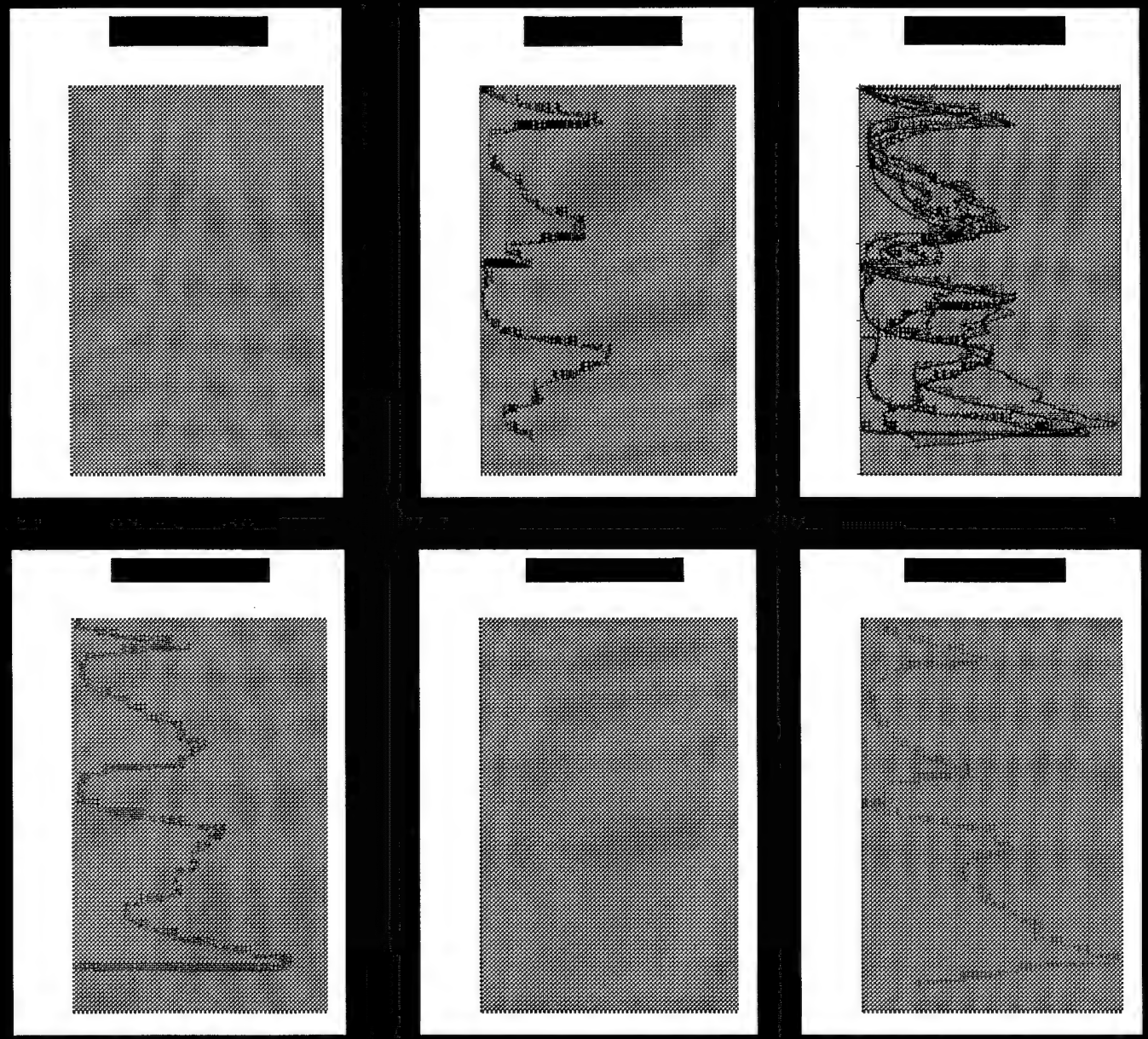


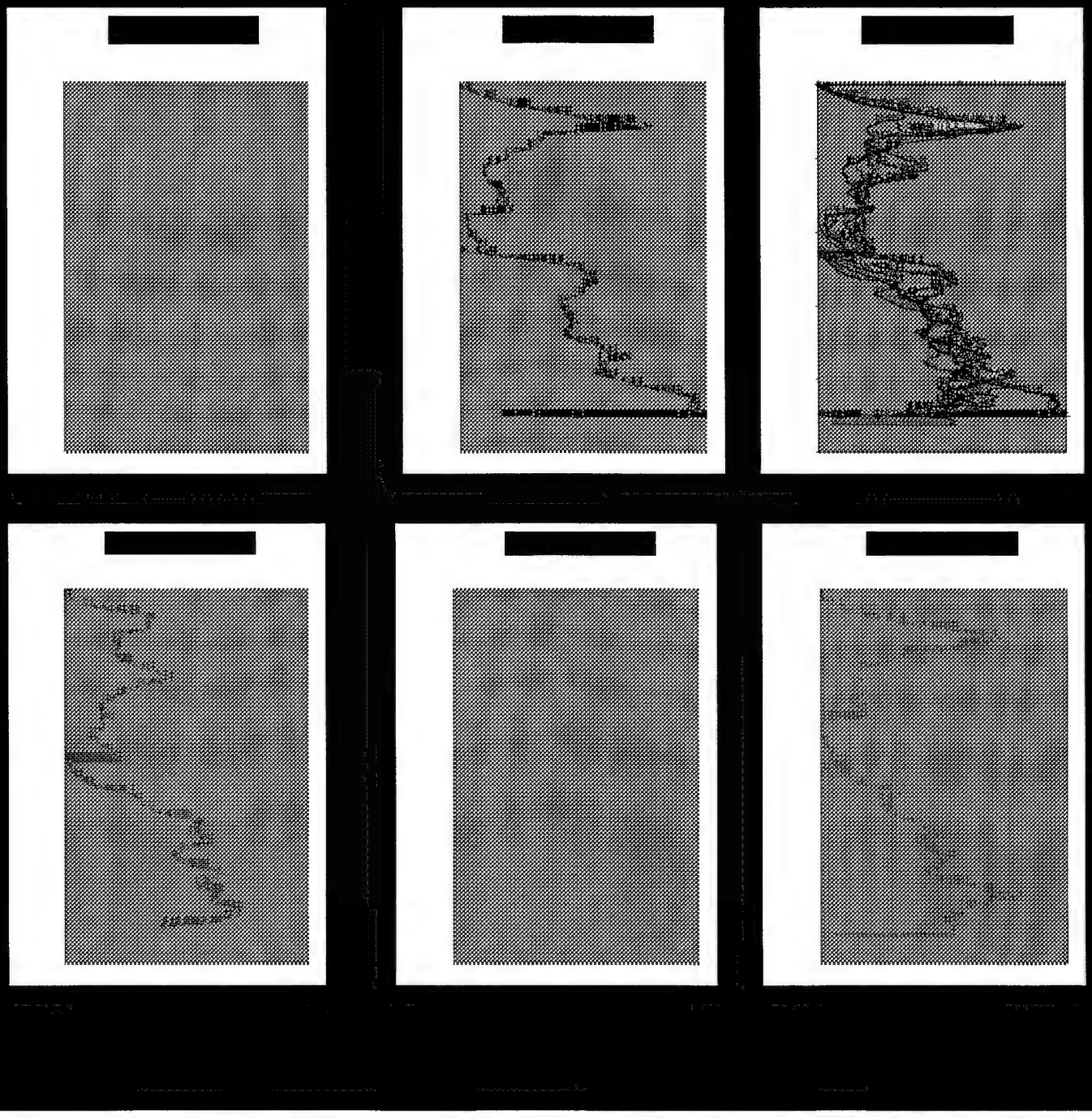


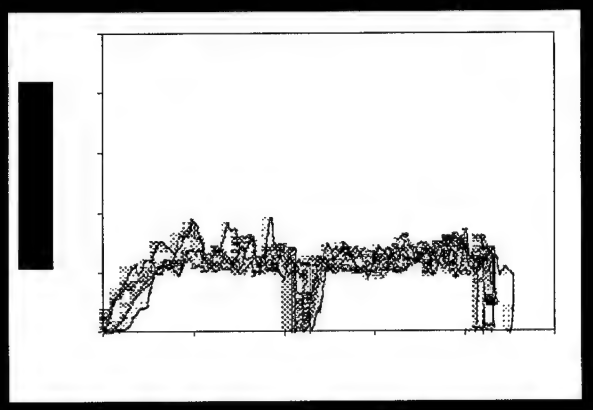


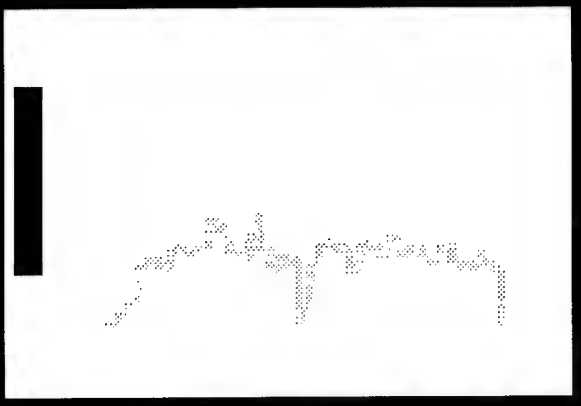


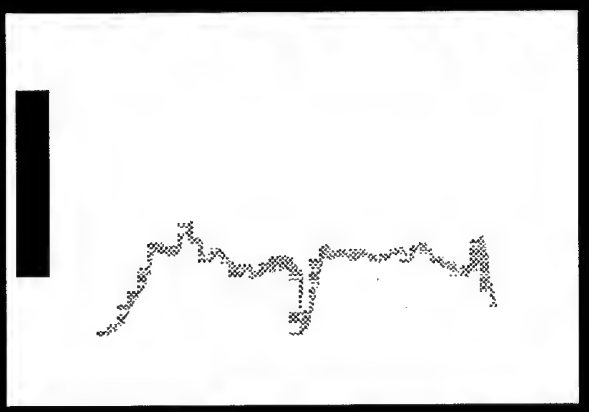


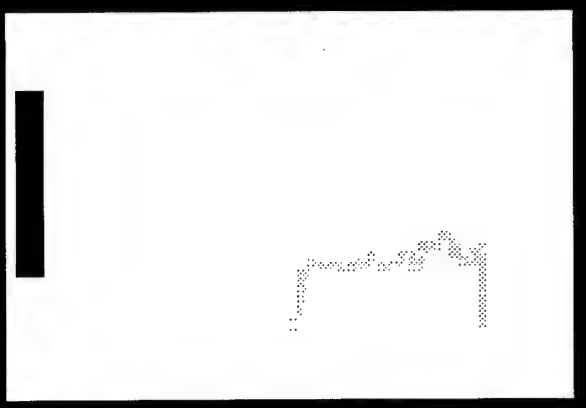


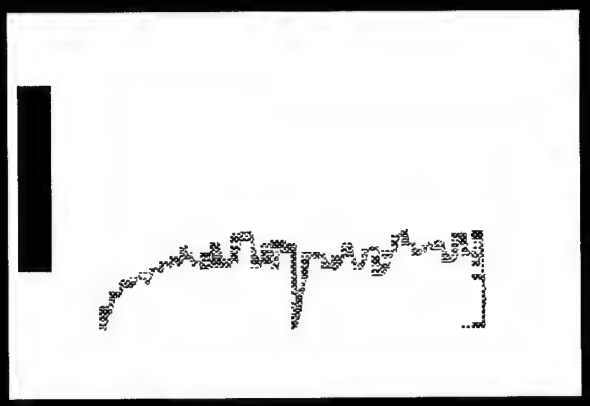


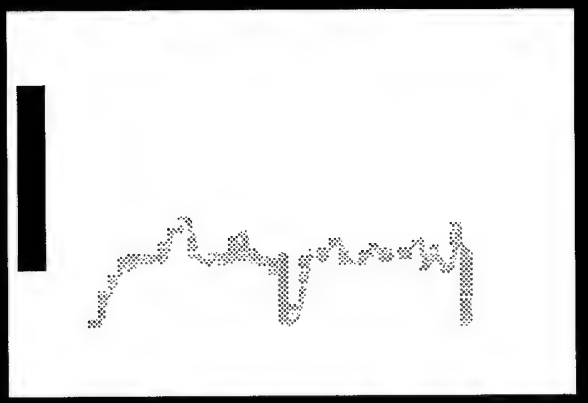


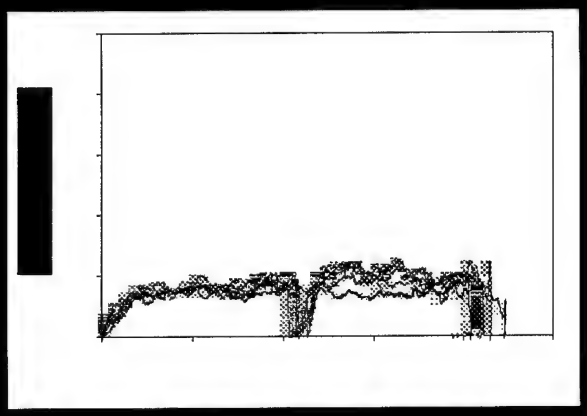


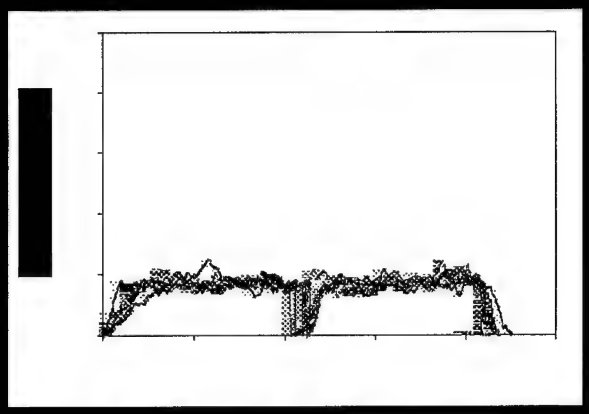


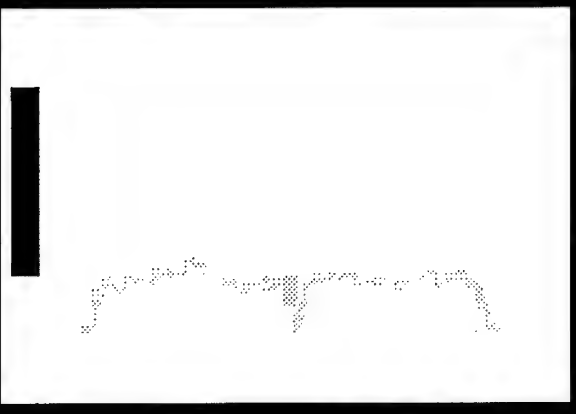


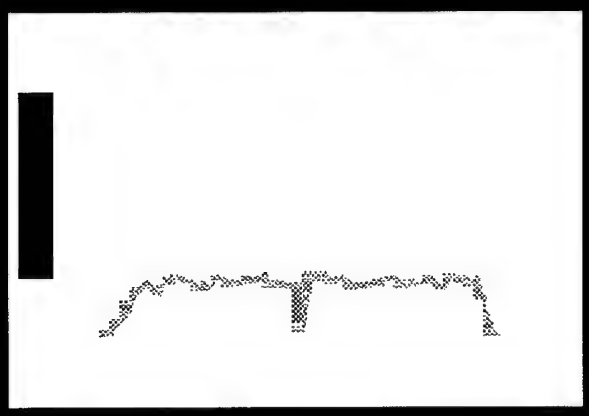


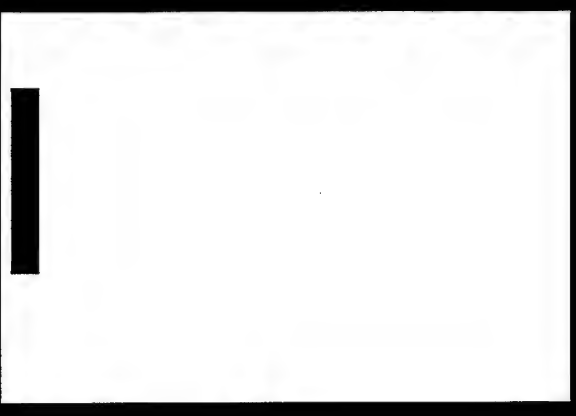


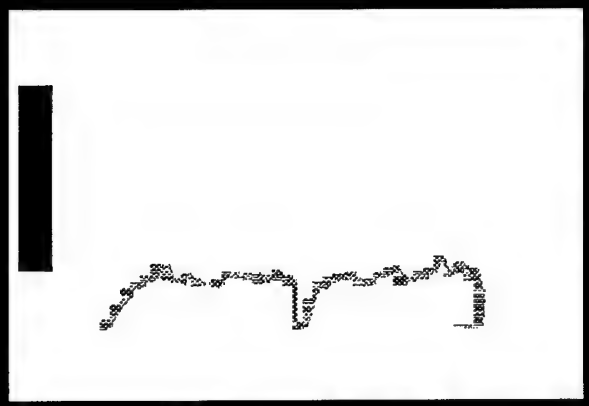


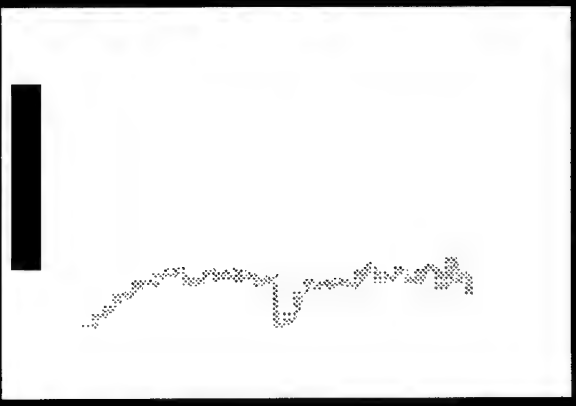


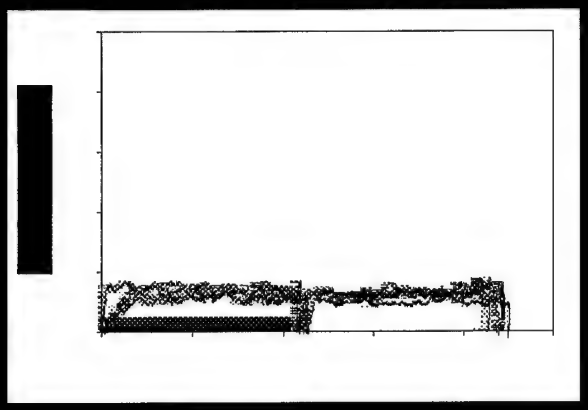


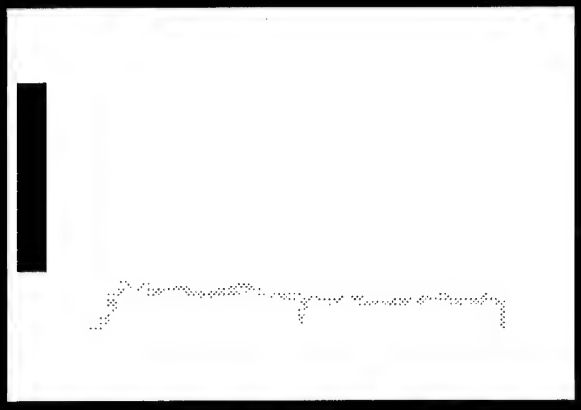


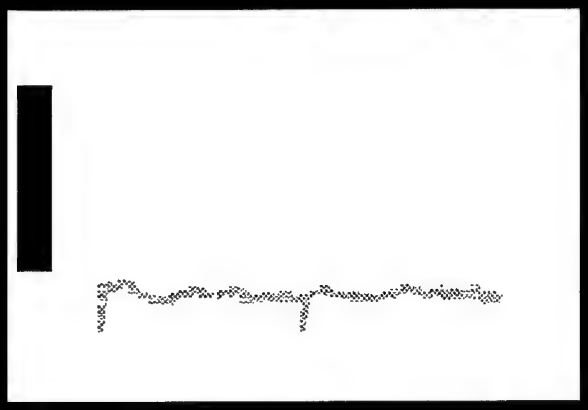


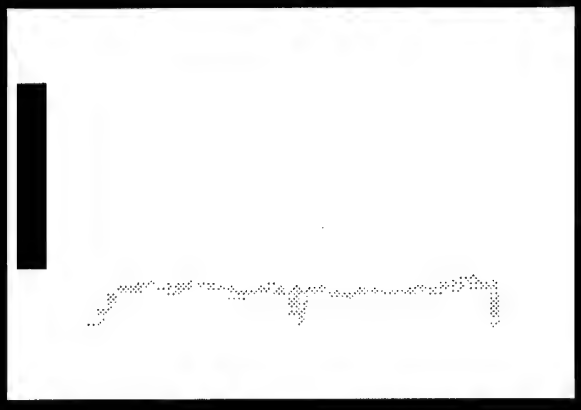


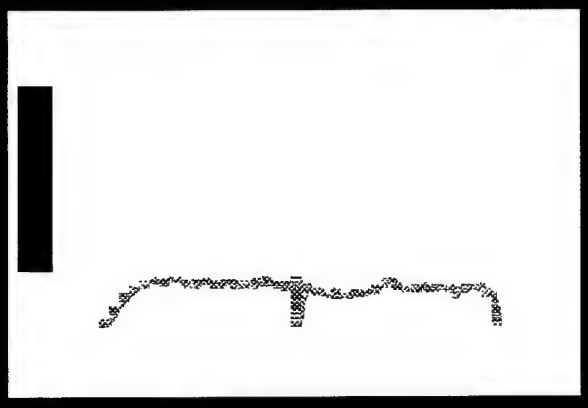


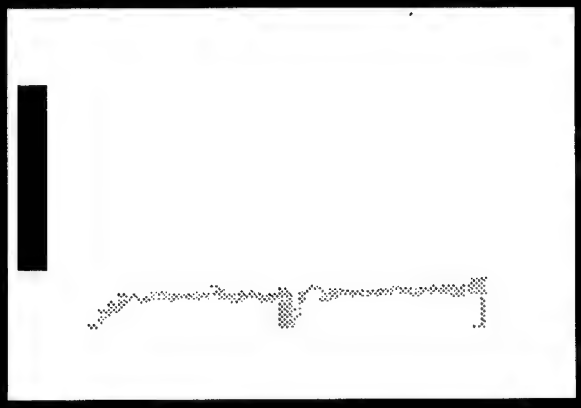


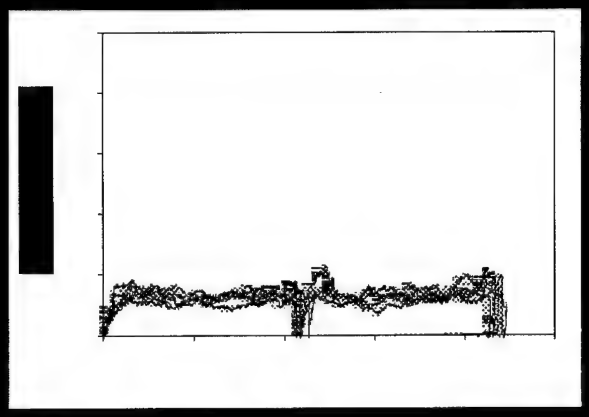


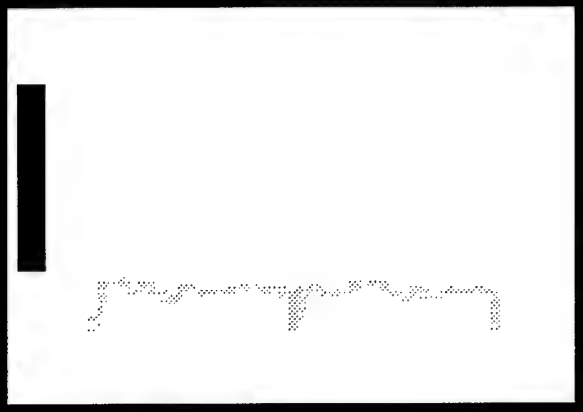


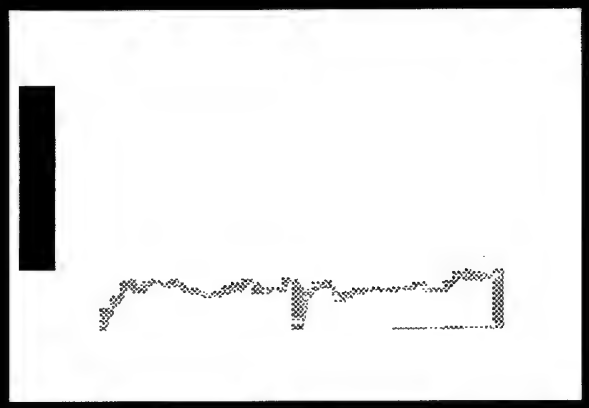


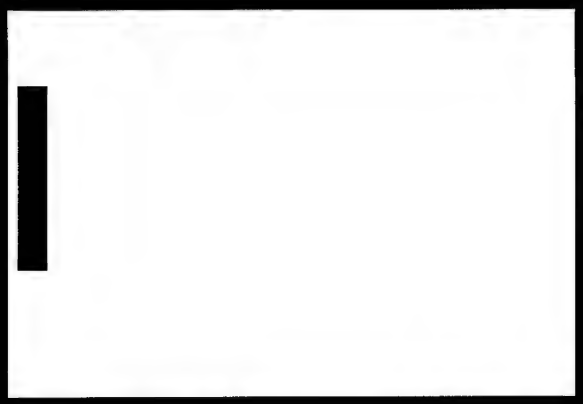


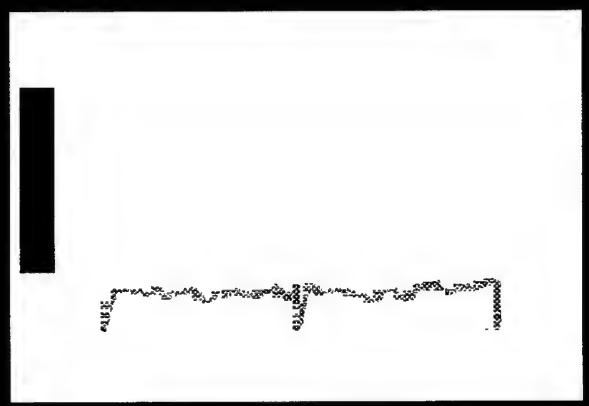


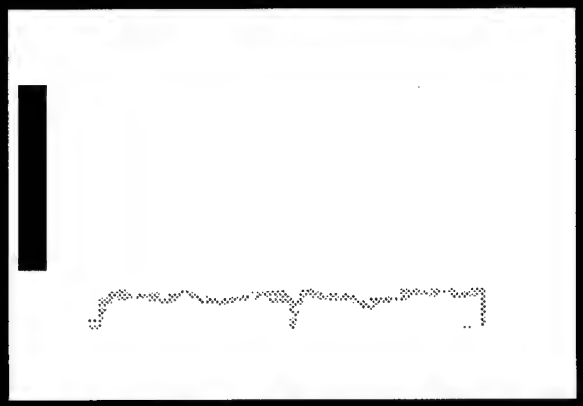












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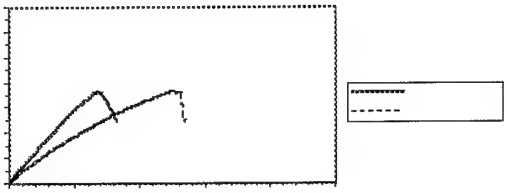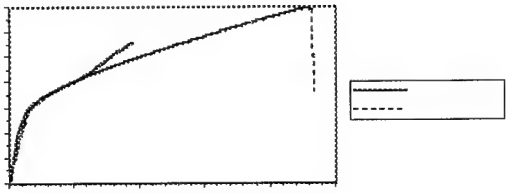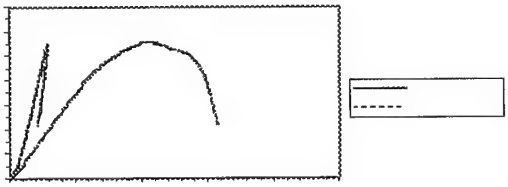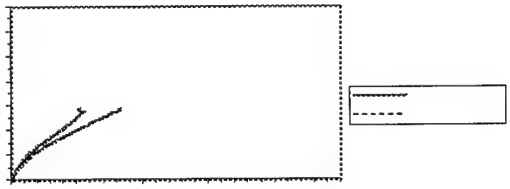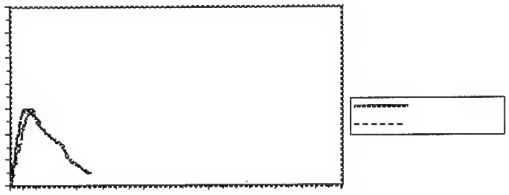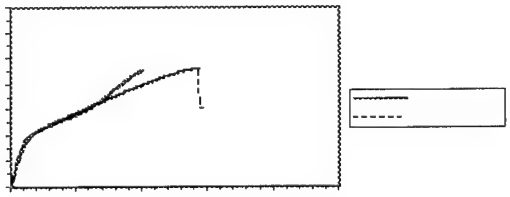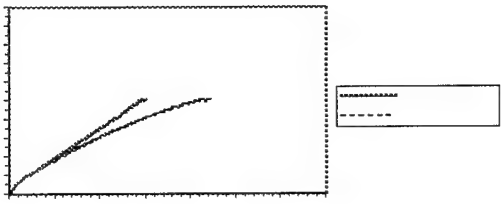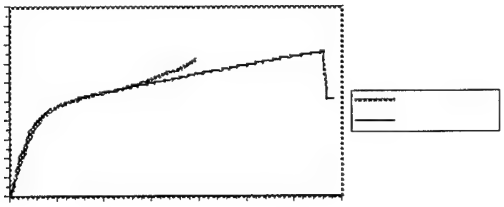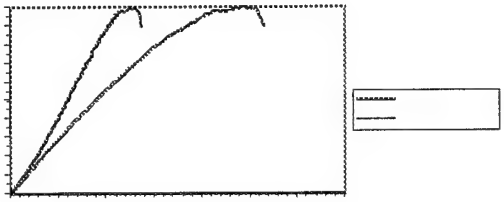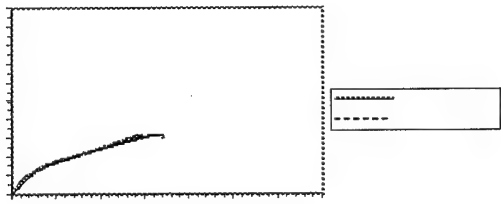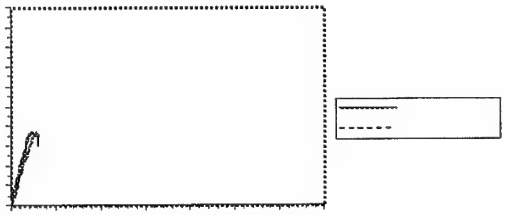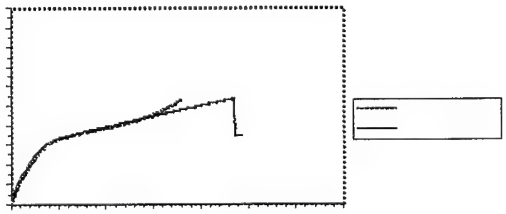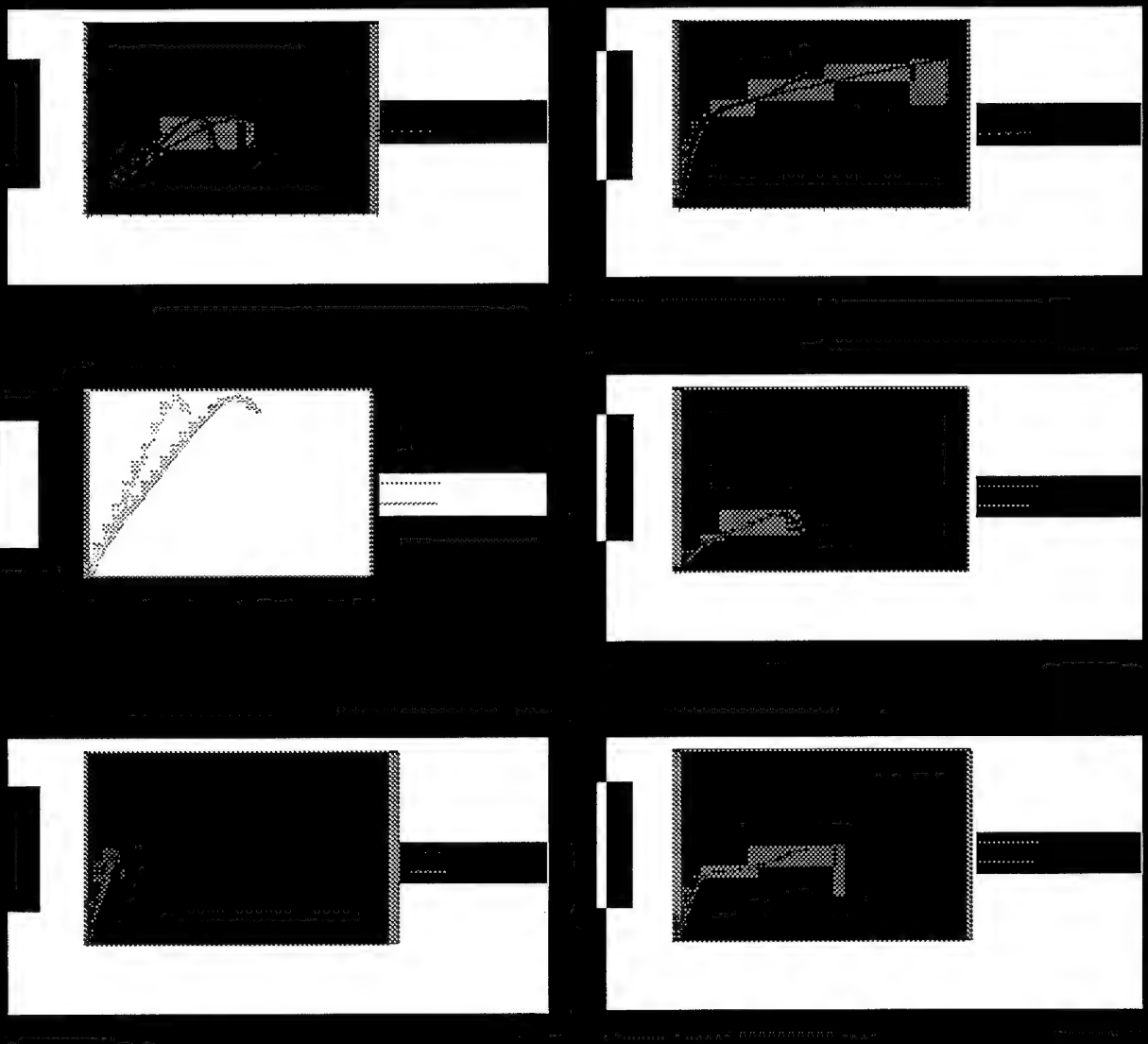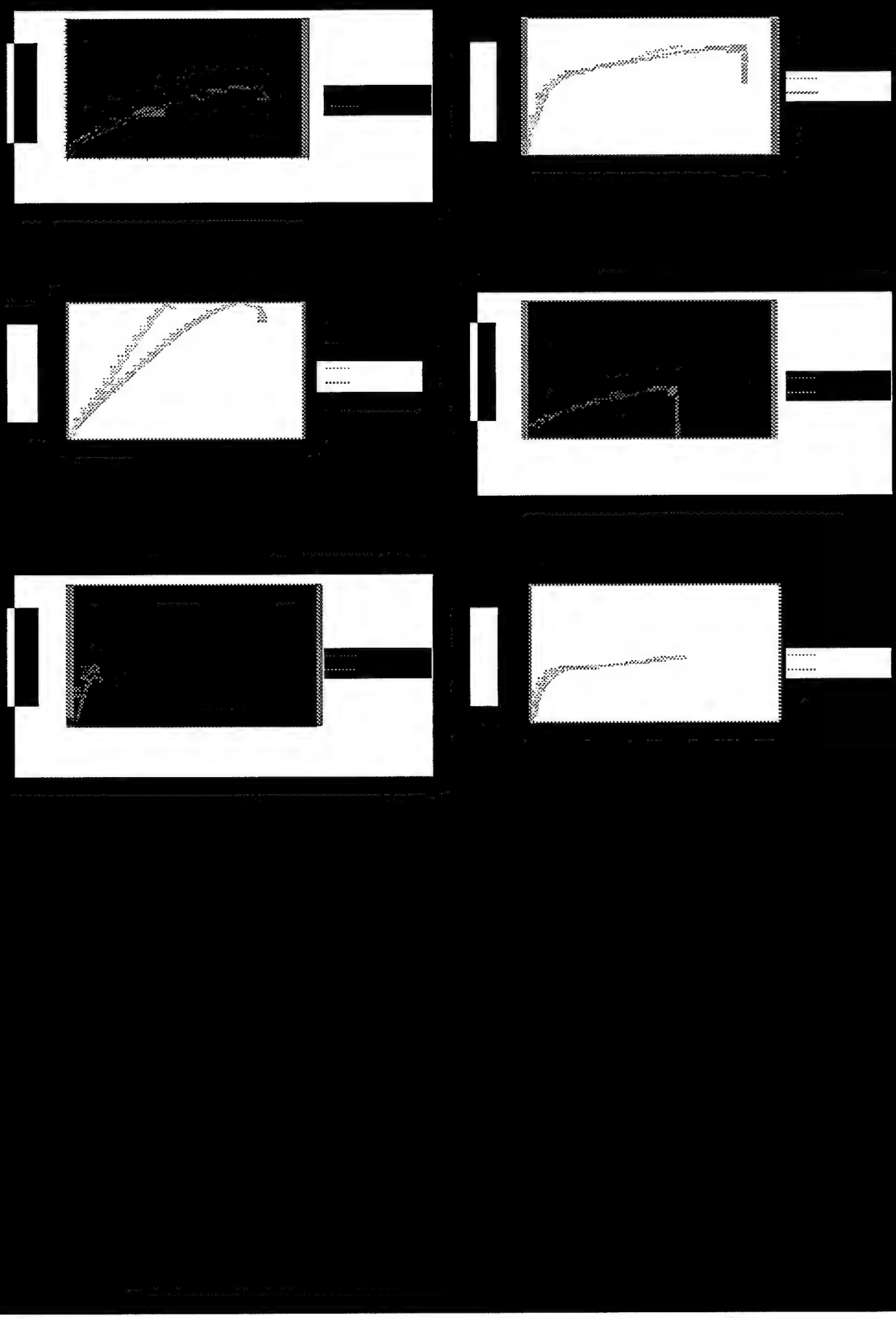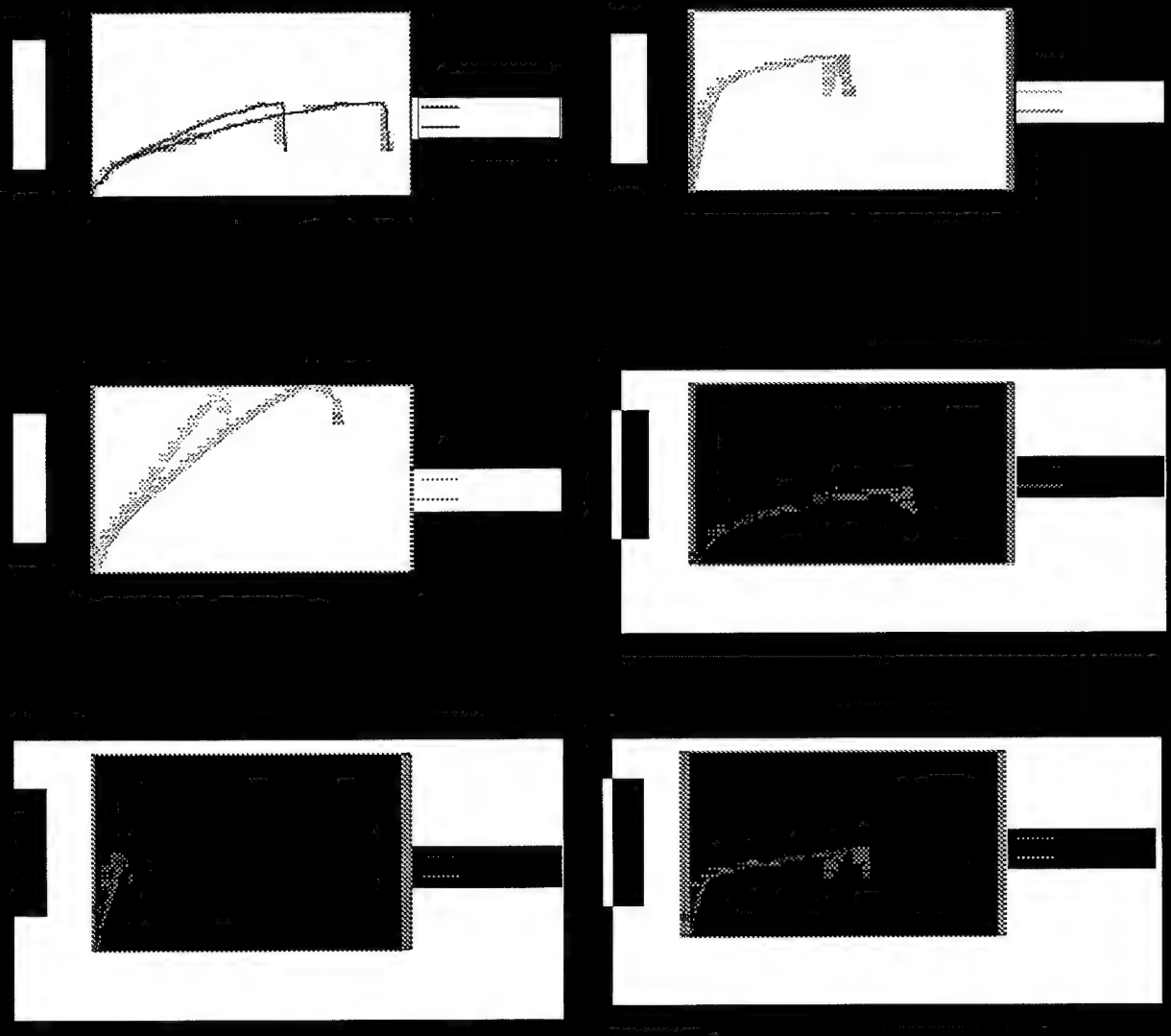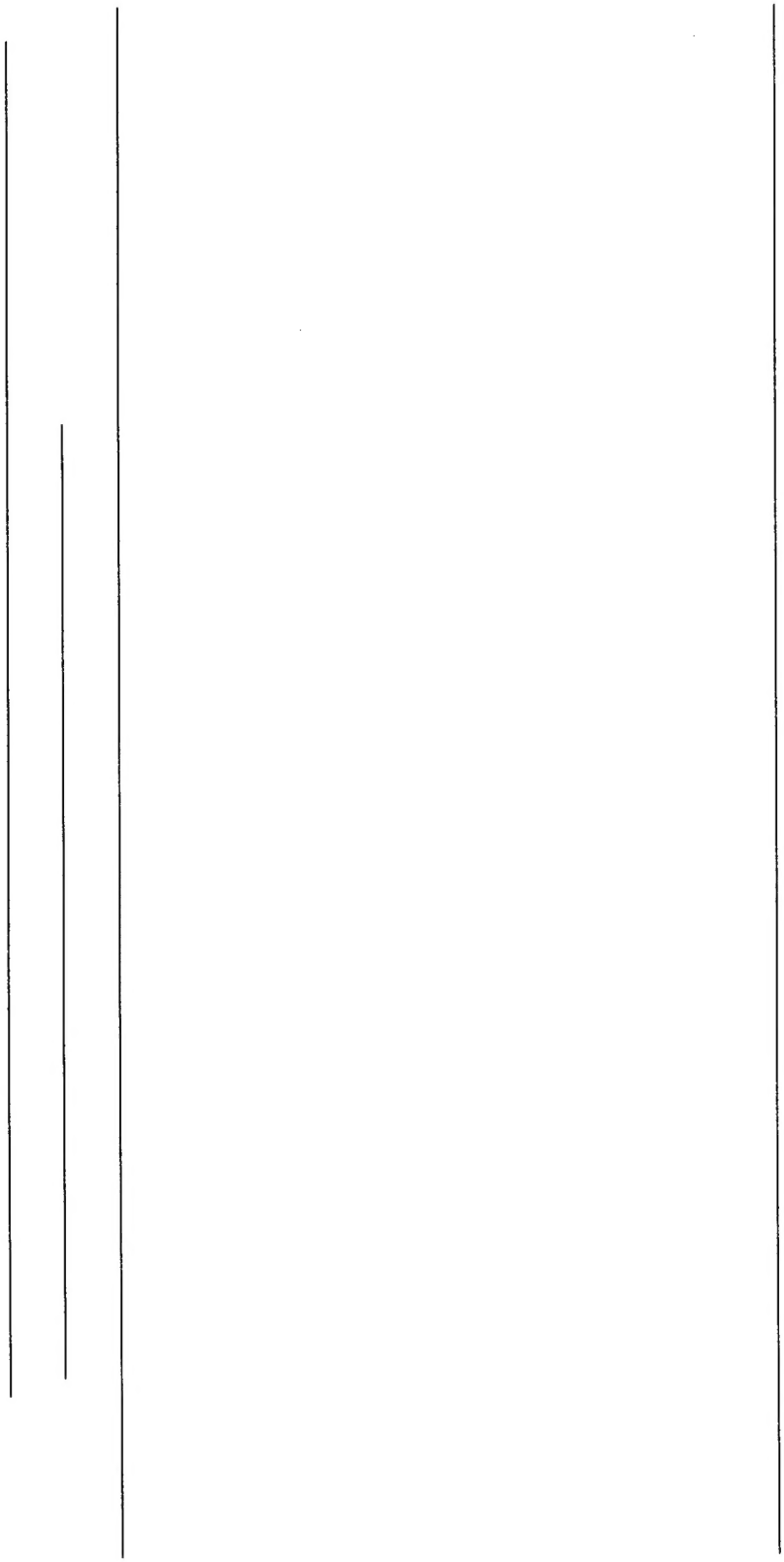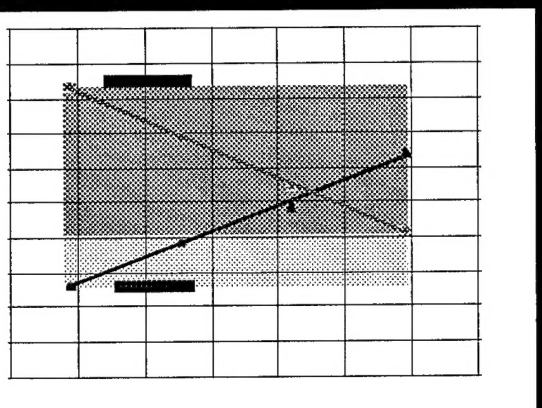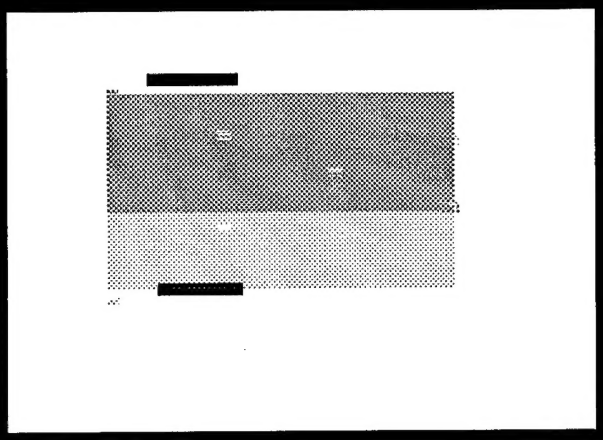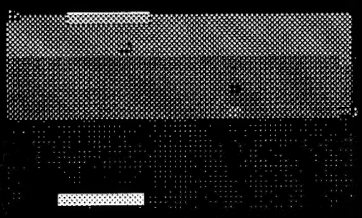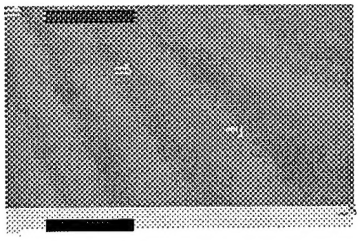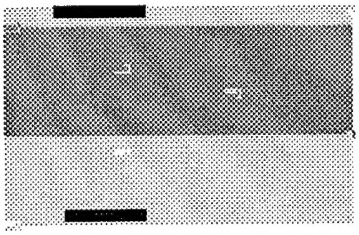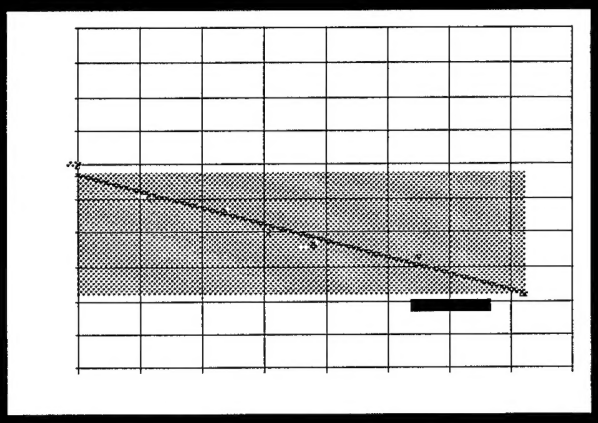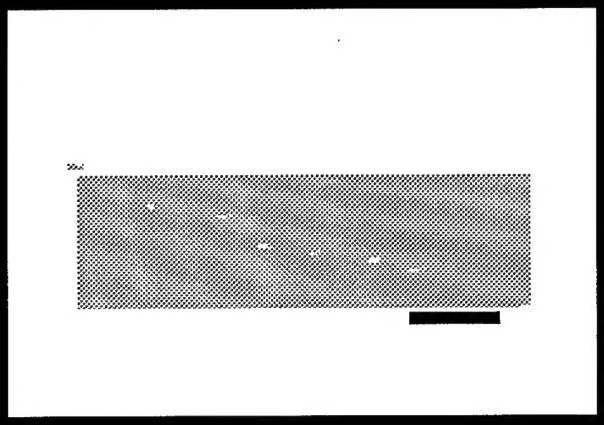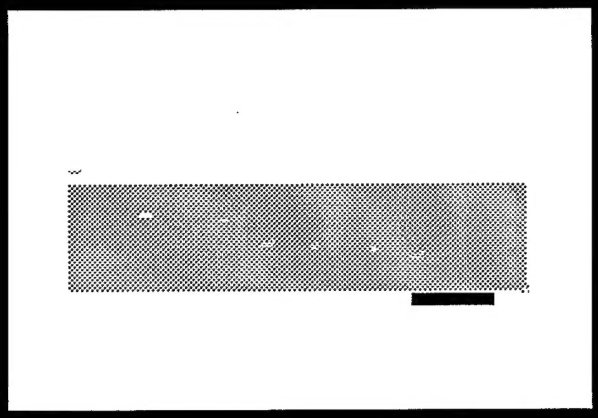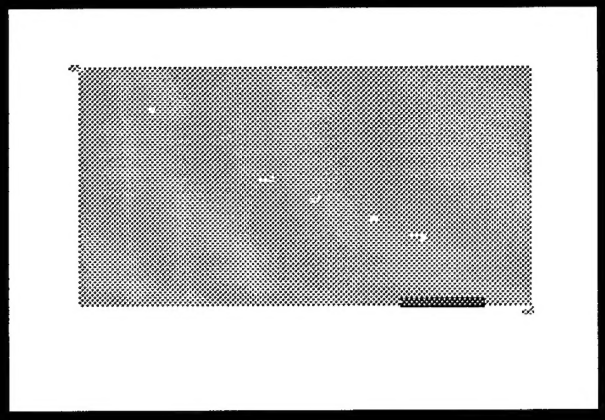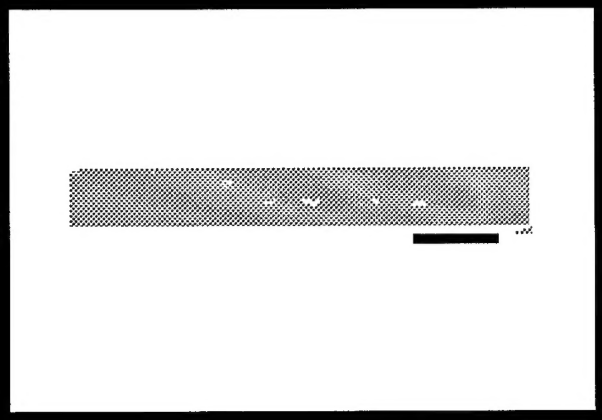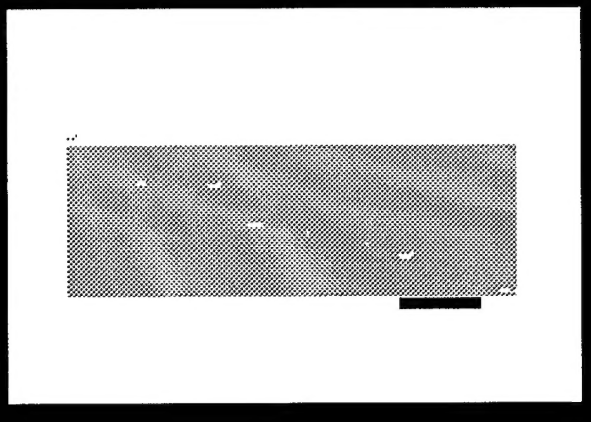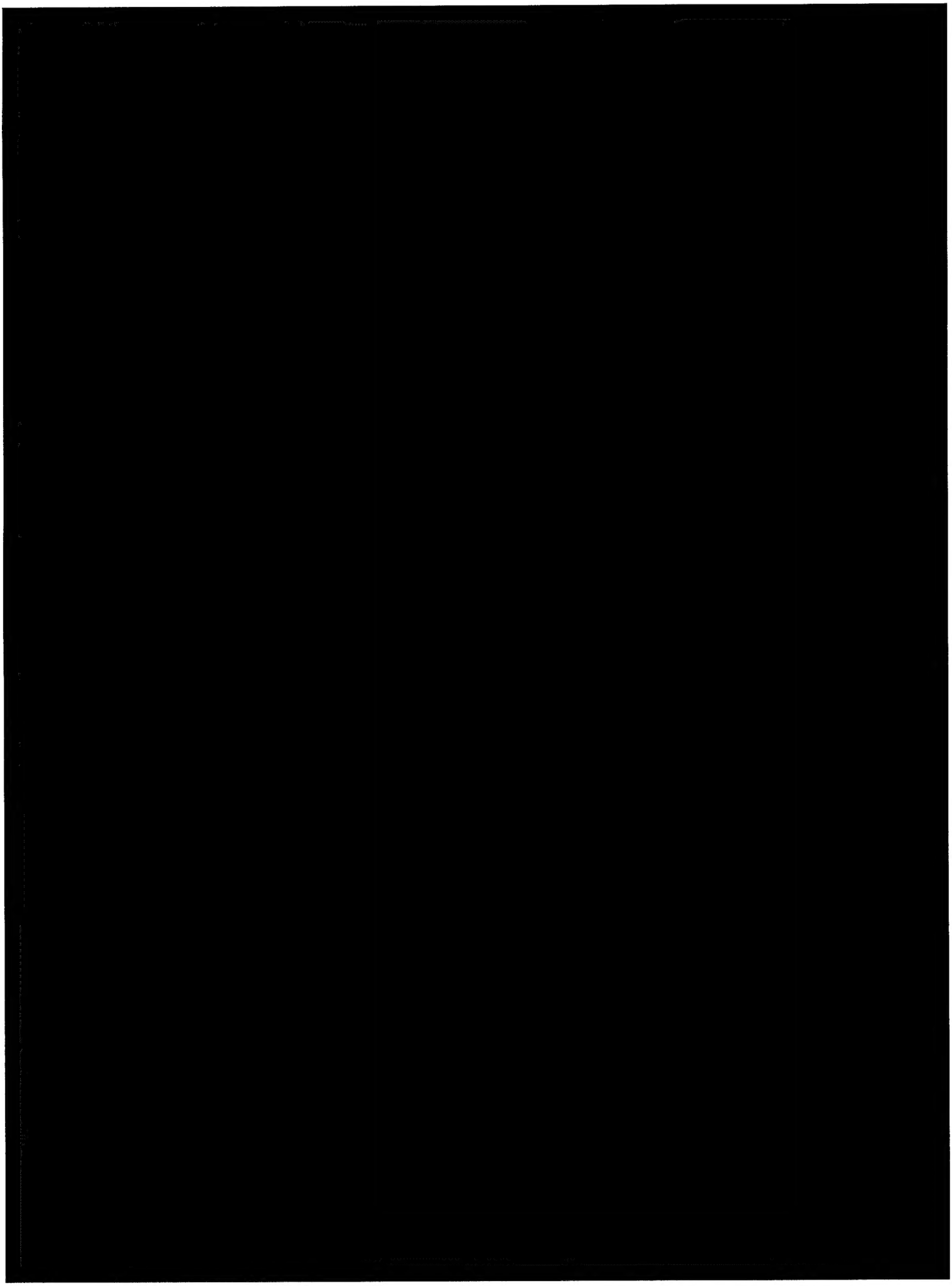
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